

**SYMPOSIUM ON TROUT
HABITAT, RESEARCH,
AND MANAGEMENT**

Proceedings
September 5-6, 1974,
Western Carolina University,
Cullowhee, NC

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TROUT HABITAT
RESEARCH and MANAGEMENT

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SEPTEMBER 5-6, 1974
WESTERN CAROLINA UNIVERSITY
CULLOWHEE, NORTH CAROLINA

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FOREWORD

Trout habitat has been degraded in the Southern Appalachians by deforestation, fire, overgrazing, dams, mining, urban and industrial waste, road construction, and poor agricultural practices. The result has been a progressive reduction in the productivity of the cold water resource and the elimination of many miles of otherwise productive trout streams from the resource base.

Wild trout and their forested stream environment are highly valued by the public. Mountain streams are receiving increasing fishing pressure; recreational use of cold water streams ranks high among the various stream values; and revenues derived from these uses are vital to the economy of this area.

Demands for other forest resources are creating conflicts and competition among user groups, resulting in difficulties in resource allocation and management. These problems will become more acute as populations expand and competition for land use intensifies. The symposium was organized to establish a dialog between conservation groups and managing agencies, to consolidate known information, and to offer a means of expressing new ideas and philosophy pertinent to management of the trout resource in the Southern Appalachians.

During this 2-day symposium, papers were presented expressing views, opinions, ideas, and facts concerning the management of trout habitat in mountain streams. Conservation organizations, researchers, and managers discussed trout habitat management programs and policies, defined major management problems, and identified present and future research needs.

It was pointed out repeatedly that the aquatic habitat of trout is a fragile environment, easily disrupted or even destroyed by man's activities on the land. However, the means of ameliorating the adverse impacts of land use on trout habitat are known to some extent, and new research offers promise of greatly expanding available knowledge in the next decade.

A number of people contributed to this symposium in addition to the qualified and enthusiastic experts on the program. Members of the Planning Committee who worked to make this symposium a success deserve recognition:

W. Donald Baker, Chief
Division of Inland Fisheries
North Carolina Wildlife Resources Commission
Raleigh, North Carolina

Marvin R. Hawes, Member
North Carolina Council of Trout Unlimited
Western Piedmont Community College
Morganton, North Carolina

Donley M. Hill, Limnologist
Division of Forestry, Fisheries and Wildlife Development
Tennessee Valley Authority
Norris, Tennessee

Robert F. Raleigh, Unit Leader
Virginia Cooperative Fishery Research Unit
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Jerry West, Local Arrangements Chairman
Department of Biology
Western Carolina University
Cullowhee, North Carolina

In addition to these willing workers, special recognition is due to two of my colleagues at the Southeastern Forest Experiment Station for their outstanding contributions to the planning of the symposium:

Michael R. Lennartz, Staff Assistant
Research Planning and Application

Thomas J. Harshbarger, Aquatic Ecologist
Bent Creek Experimental Forest

David F. Olson, Jr., Chairman of Planning Committee
Southeastern Forest Experiment Station, USDA Forest Service

KEYNOTE ADDRESS

FRANK R. RICHARDSON
ASSOCIATE REGIONAL DIRECTOR
U. S. FISH AND WILDLIFE SERVICE
DENVER, COLORADO

When I was first approached by one of the Symposium organizers to take on this assignment as your keynote speaker, the particular individual was well aware that I was an easy mark. Talking trout and getting a chance to visit North Carolina come high on my priority list. After congratulating myself on getting this fine opportunity, I found to my delight, that keynote speakers are at liberty to set their own rules. So I emphasize that the following remarks represent my own personal views. They neither represent the policy of my employer or those of conservation organizations to which I belong. They represent my philosophy and my beliefs of trout and trout fishing.

I am delighted to see that the first session of this Symposium is devoted to Public Views of the Trout Stream Resource. I have long known some of the members of this panel and one has been a close personal friend for many years. I would like to share a true story with you that involves him. I use this story to illustrate the point that public views and public participation in making management decisions on trout resources are not only good politics but better decisions are made when the public participates. I have seen too many incidents where public resource managers made these decisions behind closed doors. Now let me tell you this story. About 15 years ago I opened the trout season here in North Carolina with several friends on a favorite North Carolina stream. We were billeted in an ancient log cabin that let in most of the night air. Like so many opening days, the thermometer was below the freezing mark. That night, when readying ourselves for bed, the conversation turned to how we were going to keep warm. One of my angling friends was quite wordy in selling the merits of new electric blankets which had been installed for each bed. Another participant of this opening day was just as enamored with his new thermal pajamas which were designed for subfreezing weather. These two were sharing a room where the twin beds had each been fitted with the new electric blanket. As they adjourned to their bedroom, you could still hear their discussion of the merits of blankets versus pajamas. Unbeknown to them, someone had switched the blanket controls so that, in fact, they were regulating each others heat control. The next morning at breakfast the former blanket-lover went into great detail about the need for everyone to get these new pajamas--he had shivered through the whole night with his blanket turned all the way up, never realizing that his roommate with the thermal pajamas had turned his own controls off because he was benefiting from his partner's heat. The point of this story is that, we as Resource Managers need to know what our conservation constituent not only thinks and is doing but he must be allowed to share in the responsibility of decisionmaking.

During the past six weeks, I have taken part in two meetings--the annual meeting of Trout Unlimited in Seattle, and the Annual Conclave of the Federation of Fly Fishermen in West Yellowstone. These meetings were attended by the activist angler, the individual who wants to personally involve themselves in what happens to the resource that provides their recreation. The people who attended included truck drivers, lawyers, salesmen, doctors, resource managers, fishery biologists, and State Fish and Wildlife Commissioners and all with that common interest to do a better job of looking after the

fishery resources of the United States. Similar meetings that I attended a decade ago more often pitted the resource user (the angler) against the fishery biologist and the resource manager. Those of us who are resource managers no longer can afford the luxury of going it alone, and I use the term "luxury" loosely when it might be more proper to say stupidity.

Those of us who call ourselves conservationists have always been true believers. We often have that gut feeling that our cause is righteous, especially when what we want is for someone else. I suppose there is a certain dignity in this attitude, although I suspect that in the minds of some, our motives are suspect. I would recommend that whenever we can identify such a condition, we take a few days off and go fishing. All of which to say is that what seems both rational and moral, may not necessarily be what society wants or requires. I have long thought that trout populations are an excellent index in measuring the health of the human environment. In fact, I believe that in the evolutionary future of this planet earth when the last trout expires, man as a species will have preceded him.

Session II of this Symposium zeros in on habitat alterations. I look forward with great interest to the comments of this panel. Having seen trout streams destroyed by industrial and municipal polluters, poor logging practices, strip mining, channelization, road builders, and damming, I tend to get irrational when trying to explain these things, though continued destruction of trout habitat in the Southeast is not the big issue, as it is in the Rocky Mountain West where I live, it still is one of the hottest issues going. The demand to produce energy from coal and oil shale in the West and the need for water for energy development and the associated growth that goes with this, will in the next several years put more pressure on blue ribbon trout streams of the West than all the atrocities heaped on them from mining and damming of the past. Whole rivers may be dewatered and the Yellowstone River in Wyoming and Montana, which is the longest undammed trout stream in our country, could be lost. To put this in a better perspective, the Yellowstone trout ecosystem is larger than all of the Southern Appalachian trout ecosystem. Obviously, we are going to develop our energy resources, but when someone says its either coal or trout, I'm really turned off.

One of the legislative milestones in the conservation history of our country is the Fish and Wildlife Coordination Act. It was first signed into law in 1934 by President Roosevelt. It was subsequently amended in 1958--16 years ago. Presently efforts are being made in the Congress to strengthen this Act. The Act, in theory, puts fish and wildlife on equal standing with other natural resources--both in planning and in constructing Federal projects. Presently, the U. S. Fish and Wildlife Service and State Fish and Wildlife Agencies are brought into planning only as consultants. Other loopholes in the present Act have allowed certain projects of such agencies as TVA, the AEC, and the SCS to be only partially covered or exempt. If the Act is strengthened as proposed by some members of the subcommittee on Fish and Wildlife Conservation and the Environment, I suspect that the channelization of trout streams and other issues, such as, the Tellico--Little Tennessee River would never have occurred. For these reasons, I can think of no single legislation that will affect total trout habitat more than the Fish and Wildlife Coordination Act, and we as individuals who are concerned with this resource should support these efforts to strengthen this Act.

Each May, for the past 15 years, North Carolina and specifically Fontana Village has been hosting the Fontana Conservation Roundup. I'm sure all of you here are

familiar with this event and most of you have attended one of the roundups. When I was living in North Carolina and Tennessee, I was fortunate enough to make several of these meetings. Last year the theme of the roundup was Environmental Trade-Offs. When I hear those words Environmental Trade-Offs, my antennas really extend. I can visualize trading all the water in the Colorado River to develop oil shale, I can visualize the loss of western prairies in the United States and Canada where most of our ducks are raised to produce wheat to feed starving people in India and Africa. Maybe these trade-offs will be made, but there will be some trade-offs proposed where we must "stand in the school-house door" where the environmental value cannot be abused, where our answer must be just plain "no." Many of you are familiar with the works of Barry Commoner--I would remind you to remind yourselves once in awhile with three of his gems that he refers to as the laws of ecology--"there's no such thing as a free lunch," and "everything is connected to something else," and "everything goes somewhere."

Tomorrow morning our Symposium will address Trout Habitat Research and Management. Until a few years ago, my working day, and I should add other parts of day, revolved around Trout Management and Research. I was lucky enough to live in and work in areas--(I use the term "work" in its loosest definition)--and associate with people that daily dealt with the trout resource. Now every once in awhile I wonder where I went wrong when now my day is filled with budget reviews, personnel ceilings, coyotes and sheep, listening to the pros and cons of steel shot, and other Fish and Wildlife Service issues. Even though I am not as deeply involved with Trout Management and Research as in the past, my interest and devotion to these subjects has never wavered, I like to think that some of the things I was involved in in the past were right. However, I must confess, I have memories of some of my actions that today I find completely alien to present-day consensus of good trout management. Most biologists I know have a stubborn streak when it comes to change and accepting new ideas. It seems all of us have to try out our own ideas, even though the idea has a history of failure wherever it has been tried. (I guess I should exclude all of you gathered here today.) However, I'm sure that each biologist here in this room can identify some action in his past that he would rather forget. The "Pisgah System of Trout Management" was developed here in North Carolina, and when this System came on the scene a few decades ago, many biologists across the country claimed it as the savior to trout fishing and it was copied in many parts of the country. Today the "Pisgah System" is essentially something to read about but seldom seen used. Today we are more "sophisticated," a term I use loosely. Yet in ten years what some call good trout management today will go the way of the "Pisgah System."

Recently, a study conducted by a Montana biologist on the Madison River, at the insistence of trout anglers of that State, showed that stocking of catchables into an existing wild population of trout actually depressed both populations. Now, after years of planting catchables in this fine trout river, the procedure has been eliminated. I'm not aware of how many fish were being released each year, but I do know that significant savings in cost of Federal hatcheries were realized when the Fish and Wildlife Service stopped planting adults in the Madison River involved in this study. Now, if this could happen in Montana, it could happen here in the Southern Appalachians. With costs of producing hatchery trout having gone up sharply in the last few years, it behooves us to examine all facets of our stocking programs.

Somewhere in the past, I heard a fishery biologist say--maybe I said it--but regardless who said it, the following statement is valid--"There are many ways to manage a trout stream, but when hatchery catchables are released, you are not

managing the stream--you are managing the angler." About a decade ago knowledgeable trout anglers began to question the way we manage our trout resources. They began to organize into action groups. "Trout Unlimited" and "The Federation of Fly Fishermen" emerged about that time and recently "The American League of Anglers" was formed. These organizations have had a significant affect on how we manage trout waters. Prior to this time, "Quality Regulations," "Fish for Fun," "Catch and Release," or whatever name you want to apply, just did not exist in public waters. In fact, as far as I can determine, the Great Smoky Mountain National Park was the first public area to implement regulations that, in theory, said that a trout fishing experience is more important than catching trout. Still in some trout fishing programs, it seems that if you don't kill your limit your fishing trip has been a failure. It seems that many managers base the success of the trout fishing program on the creel success.

I'm sure that most of you here know of Hazel Creek in the Smokies. During a period from 1963 to 1969, I directed a fishing success census on this stream. Hazel Creek feeds into Fontana Reservoir and access is either by boat or dropping off the Appalachian Trail. If I remember correctly, during that 6-year period, fishing pressure ranged from 3,000 to 5,000 angling trips a year; catch rate was 15 to 19 per day, and the creel stayed at 2 per day. These data suggest that nearly 100,000 fish were caught one of those years. As I recall, there are about 70 miles of fishable water in Hazel Creek watershed, which means that about 15,000 trout were caught per mile. Another figure I seem to recall, was that a permanent sampling station which we looked at each year, indicated that Hazel Creek supported about 2,000 legal trout per mile of stream--that is, 2,000 trout were 7" or larger. Of course, there are many trout under 7" and they make up a significant part of the catch. However, I think you can safely say that Hazel Creek is a stream where trout obviously may be caught and released several times. The points I'm trying to make are that, (1) today a trout is more valuable in a stream than it is in a wicker basket and, (2) that you can have a good trout fishing where heavy pressure exists without stocking.

Now before I get carried away and suggest that we close up all of our hatcheries, let me make it clear that I take no such position. We have many needs for hatchery produced trout. Presently, the U. S. Fish and Wildlife Service is conducting a Blue Ribbon study of national hatchery needs. The study group is headed by Dr. Alex Calhoun, recently retired Chief of Fisheries of the State of California. He is being assisted in this study by both Federal and State biologists. I would expect that this report will set the trend in what we do in hatchery production during the next decade.

It seems to me that our trout research efforts have always taken a back seat to what we call management. If you looked at the total dollars spent on research as opposed to that spent on management and I would have to include hatchery production in the management category, you find that a very high proportion of the dollar is spent on management. In general, most trout States have weak research programs in regard to trout. Even the U. S. Fish and Wildlife Service, who have historically done much of the research in the fish and wildlife field, spends only a small percentage of its fishery resource budget in trout research. In fact, in the one issue that is questioned most by trout fishermen we have no formal research program, and that is--What affect and success does stocking have on trout fishing? Yet we are beginning to make inroads into the unknown. The Montana Madison River is one example. The U. S. Fish and Wildlife Service's Beulah, Wyoming Research Center is another. At Beulah, we recently initiated a comprehensive research program on the genetic problems associated with stocking fish. In the past we have selected fish in our hatchery program that do well in hatcheries with little or no concern of how well they do in the wild. Instead we should have been doing the exact opposite.

In closing, I want to emphasize the following points:

1. We have much to do if we are to have trout fishing in our future. The public will have to maintain its vigilance so that we are assured that sound trout programs are supported at a level needed to maintain fishery habitat--which means cold, clear water. Management and research must be realistically supported by tax dollars if we are to do justice to the trout resource.
2. The trout resource must be recognized as a national resource. We have a history of seeing their value being ignored when in competition for water use. The trout resource must get a "better shake" in regard to water development projects.
3. Fishery management must be based on sound information produced by research efforts, not ill-founded opinion.
4. We must strive for quality in our programs.
5. Finally and most important, protection of the trout environment is absolutely essential. This environment has to be maintained, not only for trout but for our own existence.

IEWS AND SUGGESTIONS OF N.C. TROUT UNLIMITED
ON TROUT HABITAT

Marvin R. Hawes^{1/}

Abstract.--North Carolina trout streams are continually being flooded and silted as a result of land development, logging, mining and road construction. North Carolina Trout Unlimited welcomes research into anything that affects trout streams, urges better cooperation between agencies, and supports programs to restore trout streams to their natural condition.

Trout Unlimited's North American Policy for Salmonid Use and Management states the belief, "that the overall quality of trout and salmon fishing has deteriorated in many areas and that drastic and immediate action is required to restore it (Trout Unlimited 1964)." This is certainly the view of Trout Unlimited in North Carolina. Dean (1974) points out that, "the Cane River, Thompson River, Jacob's Fork, Linville River, South Toe River, Upper Creek Steels Creek, Caney Fork, Nantahala River, South Mills River, and Green River are either already or may soon be in trouble." Dean goes on to say that these are not the only and it would be virtually impossible to name all the streams that are threatened with deterioration or destruction.

The primary cause of the degradation of these trout waters has been continual siltation from the exploitation of the Southern Appalachian Mountains by land developers, loggers, mining and road construction. North Carolina Trout Unlimited realizes that other sources of pollution have hurt some of our streams. But, the continual flooding and siltation of our streams has resulted in thick build ups of silt in the bottoms of our streams. Needham as far back as 1938 pointed out the potential harm to trout habitat by sedimentation. Later work has shown that fine materials in or on redds cuts down on the amount of oxygen laden water that can flow past the eggs as well as preventing easy egress from the nest by young (Needham 1938).

Trout fishermen in North Carolina have continually had to fight against the siltation of our streams. One source of siltation is stopped just to find another. Steels Creek and Upper Creek in Burke County have been seriously damaged by the construction of the unneeded Highway 181. Thanks to the cooperation of the U.S. Forest Service, the North Carolina Fish and Game Commission and the North Carolina Highway Department, hopefully the damage to these two native streams has been held to a minimum and that the damage is reversible. We are now faced with the additional siltation of these two streams by logging operations. The most recent was started last month (August 1974) on U.S. Forest Service land. A steep road was cut to Steels Creek, a bridge built across the creek, and the road continued up the other side. No representative from the U.S. Forest Service was present to supervise this, or it might have been prevented. Another incident was the development of several hundred acres in the South Mountains of Burke County along Jacobs Fork. Land was cleared, numerous roads bulldozed up the sides of mountains, and several hundred yards of stream bed and surrounding banks were completely altered by a gravel mining operation.

The development of the Linville-Grandfather Mountain area has seriously damaged the Linville River. Areas along Upper Creek, and Lost Cove Creek are what one might call boulder fields. These are areas that continual flooding has destroyed the vegetation along the stream. This has resulted in the stream becoming wide, shallow and the bottom covered with silt.

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Our streams in the southeast are unique. Generally, they are small, fast flowing streams and with one exception they are not limestone streams. This decreases their productivity and probably makes them extremely fragile ecosystems.

We of North Carolina Trout Unlimited would like to see research into anything that effects our streams. We need research in the following areas:

1. Productivity of our streams, including taxonomic and population studies of the organisms present.
2. Methods of increasing the productivity of our streams.
3. New methods of logging and road construction, that will effectively decrease flooding and siltation.
4. Stocked vs. unstocked.
5. Stream development and improvement.

We need better communication and cooperation between federal, state, and local governments and conservation organizations.

There is a definite need for a Mountain Land Management Act and county by county land use ordinances that will have enough teeth to stop the deterioration of our streams.

Finally, we need programs that will restore our cold water habitats to a condition in which we can realize their full potential as trout streams.

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OUR VANISHING TROUT STREAMS - A
SOUTHERN APPALACHIAN DILEMMA

Gerald D. Schuder, Sr. 1/

Abstract.--Man, and his manipulation of the environment, continues to diminish the available trout habitat in the Southern Appalachian region. The primary factors demeaning the cold water streams are: Channelization, improper timber harvesting, degrading agricultural practices, dams, increased development of watersheds, and mining.

The Virginia Council of Trout Unlimited is vitally concerned with the accelerated decrease in cold water habitat in the Southern Appalachian States. This loss of habitat is dramatically illustrated by the shrinking of the area classified as cold water watersheds in Virginia. In colonial times, trout habitat boundaries included the entire region west of the Coastal Plain. Many productive trout streams were found in the Piedmont Plateau and westward. The first great impact on the cold water fishery came with the westward movement of settlers, with the subsequent clearing of lands along water courses. The removal of shade trees along streams, and the deforestation of the watersheds for agriculture, abruptly changed the essential character of the streams from cold water to warm water habitat. Today, after 367 years of continuous development since the original colonization, the sole remaining sanctuaries for the Salmonids in Virginia are in the Blue Ridge Highlands and the Appalachian Plateau. It is with this historical background that Trout Unlimited in Virginia faces the task of protection, enhancement and restoration of the cold water fishery.

DEFINITION OF THE RESOURCE

Before any area wide cold water management programs are undertaken, the quantity and quality of a region's streams must be defined. After a proposal made by Trout Unlimited, the Virginia Commission of Game and Inland Fisheries is beginning a three-year study to classify the trout streams in the Commonwealth. When completed, this program will have cataloged all of Virginia's trout streams according to productivity, resident fish species, and aesthetics.

AN OVERVIEW OF THE PROBLEMS

In Virginia, the major threat to the cold water resource is improper land use planning and management. I will identify the primary degrading factors.

Channelization

Channelization has a long history in Virginia, being practiced since colonial times on a small scale. It was only after the flooding caused by Hurricane Camille in 1969 and Hurricane Agnes in 1972, that channelization reached massive proportions in Virginia. In the aftermath of these floods, the Soil Conservation

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Service, the Agricultural Stabilization Conservation Service, and others, indiscriminately channelized over 500 miles of 80 different streams. The impact of this work was largely felt on the cold water streams of Western Virginia, where 90% of the projects were done. The primary degradation to the fishery has been the loss of habitat and siltation.

Timber Harvesting

The nationwide shortage of wood products has extracted a heavy toll on Virginia's trout streams. The practice of clearcutting, in particular, has caused the loss of many fine brook trout streams due to siltation and increased water temperature. Very little attention has been given to providing proper buffer strips along streams, or to stabilization of cut over areas and access roads. The problem is caused by lack of supervision of contractors on Forest Service lands, and by the total lack of control of Silviculture on private lands.

Agriculture

In an attempt to gain maximum production from agricultural lands, producers in Virginia have caused many acute problems for the streams of the western portion of the state. Foremost among these are excessive use of fertilizer and elimination of streamside cover due to livestock grazing and clearing for crops. Erosion problems are common due to the lack of contour farming and the elimination of buffer strips. Feedlots located directly on stream banks are a common source of pollutants in valley areas.

Dams

If all the dams planned by the Corps of Engineers, power companies and the S.C.S. were completed in Virginia, not a single major watershed in the mountains of Virginia would be spared. The Corps of Engineers alone has 25 major impoundments in the planning stages in Virginia. The impact of these projects, if carried through, would change the character of the surface water resources in Western Virginia from riverine to still water impoundment ecosystems. The only remaining trout habitat would be in the small headwater streams.

Recreational Development

A recent threat to the watersheds of the Blue Ridge and Allegheny Mountains of Virginia is the increased recreational use of the area. The mountains represent an attractive playground for the nearby urban masses from major cities like Washington, D.C., Baltimore, and Richmond. The recreational utilization takes the form of campgrounds, individual camps, and large planned recreational developments such as Massanutten and Wintergreen. The inevitable result is enrichment, siltation, and warming of headwater streams.

Mining

Acid mine drainage is not a major threat to the cold water streams in Virginia at this time. However, in our sister state of West Virginia, it is a problem of significant proportions. The new emphasis on increased coal production as an answer to the "energy crisis" could cause a dramatic increase in the problems associated with mine drainage, particularly with strip mining techniques. This is a situation that will require careful scrutiny by wildlife professionals and conservationists alike.

DEVELOPING SOLUTIONS

Education

Trout Unlimited sees the lack of understanding of the interrelationships in a watershed as the most important factor to be considered in any plan to conserve the cold water fishery. This lack of understanding permeates all levels of those associated with watersheds, from the resource manager down to the individual citizen. The logical first step in solving this communication problem is a program that encourages an exchange of ideas and a discussion of problems between the different disciplines at our colleges and universities that offer natural resource training. The agronomist should understand the effect of agriculture on the aquatic ecosystems. The fisheries biologist should have a knowledge of the problems of the agricultural producers. All of the natural resource endeavors should be included in the exchange of ideas, including forestry, wildlife biology, mining, engineering, agronomy, and others.

The educational process that began with the exchange of information between disciplines in the academic centers must then be expanded to include supervisory personnel, field personnel, producers, and citizens groups. This can be accomplished by arranging regional seminars, where land use planning can be discussed in a public forum. An effort should be made to include representatives of local, state, and federal governments in these discussions. Members of federal and state natural resource agencies should also be involved. Understanding of interrelationships will lead to cooperative solutions to watershed problems.

Alternatives

Any conservation effort that plans to "lock up" the nation's resources is doomed to failure. A successful approach to solving environmental problems is to encourage practices that utilize natural resources in a way that minimizes environmental damage. An exception to this philosophy would be required in the case of some fragile native trout streams and unique quality waters, where total preservation of the watershed is required.

To oppose a practice without suggesting an alternative is a completely negative way to approach any natural resource problem. In the case of every practice that degrades trout habitat, an alternative is available. Channelization is a good example of the possibilities of this kind of approach. The conservationist must be concerned with the problems of flooding and erosion. However, he can offer the alternatives of reforestation of the watershed and flood plain zoning as the answer to flooding problems, and riprapping and planting of streamside vegetation as the cure for erosion. Thereby, the problems are addressed, and damage to aquatic habitat is minimized.

MANAGEMENT OF TROUT STREAMS

After the problems of habitat degradation have been dealt with, we must face the question of how our trout streams should be managed, in order to optimize the resource. The Trout Unlimited North American Policy for Salmonid Use and Management contains a sound plan. This policy addresses all parameters of trout stream management, including administration, habitat maintenance and improvement, protection of rare species, protection of unique waters and selection of management species. It is the position of Trout Unlimited that waters that have the potential for reproduction of trout be managed as wild trout habitat. and that "put and

take" stocking of trout be limited to marginal waters. The emphasis should be placed on establishing biologically sound quality fisheries, rather than the poor substitute that "put and take" fisheries management provides. Regulations should be established for each type of stream to optimize the population of trout. An ideal formula for the administration of a region's cold water fishery is to classify, protect, manage, and restore.

THE FUTURE

I would like to suggest that a yearly trout forum be established in the Southeast. It is not enough to merely identify the problems associated with trout habitat and management. A continuing program to develop and implement solutions must be established. We, the wildlife professionals and conservationists who have a direct interest in trout habitat, are the best hope that the wild trout will not be added to the endangered species list in the Southern Appalachians.

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Trout Unlimited, 4260 East Evans Avenue, Denver, Colorado 80222.

TROUT, ITS HABITAT, AND THE FISHERMAN

Fred R. Dorsey^{1/}

Regulations should be geared to the trout and its habitat to produce a quality fishery.

The fisherman has little or no effect on a trout's habitat. The only way to destroy a trout fishery is to destroy its habitat. Quoting from Dr. Frederic F. Fish, former assistant chief, Division of Inland Fisheries, N. C. Wildlife Resources Commission writing in Wildlife in North Carolina, August 1969. "The estimated contribution to the total trout harvest made by hatchery-propagated yearling trout simply will not support a contention that hatchery fish of this size constitute essential protection against extermination of the wild trout. Wild trout are exterminated by destruction of their habitat and, while fishing success may be greatly reduced through intensive hook-and-line fishing, the fish themselves will not be exterminated. Hatchery-propagated yearling trout are just too expensive a commodity to be employed merely as insurance for wild trout which are perfectly capable of fending for themselves."

One of the best illustrations of trout fending for themselves is found in the Rocky Broad River. This is a stream which runs alongside a main highway and is fished heavily all season (any lure). In spite of this pressure this stream continues to yield native fish in numbers comparable to the so-called native streams where bait is prohibited. I can cite many more examples, such as Green River, North, East and West Forks of the French Broad. (North Fork is now classified as native). Many others continue to produce trophy size trout in spite of heavy fishing pressure, all types of bait. Please note, no attempt is made to modify the trout's habitat.

The reason I mention this at this point is the fact that some attempts have been made on private streams in Western North Carolina to alter the trout's habitat. The feeding of trout has been undertaken with a great deal of success, but I am certain that this is very expensive.

These streams are not open to the public, but to only a selected few of the owners' friends. Flies and/or artificial lures only are permitted. The great success is enjoyed only by a few. These same individuals bemoan the fact that many of our streams are still open to the bait fisherman. They tend to forget that only 13% of the trout fishermen use only artificial lures. They also do not mention the prohibitive cost involved in feeding approximately 2000 miles of trout streams. I shall never forget the trip I made to one of these private streams. Neither can I forget the other thousands of trout fishermen who are unable to enjoy these paradises. Please allow me to recount another trip to a "virgin" trout stream which I made a few years ago. Needless to say, I had visions of huge rainbow trout or monster brown which would break my 4-lb. leader without any effort. It didn't take many casts to realize that the ideal trout stream is not one where the taking of trout is prohibited.

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I caught many beautifully colored rainbow trout, some of their bodies were practically all red. They had huge heads with very small bodies, most averaging about 6-8 inches. I vowed never to forget this important lesson. The trout is a renewable resource; unless there is a reasonable harvest, the available food is quickly consumed, resulting in a stream full of runts.

Our wildlife biologists are certainly aware of this situation and yet, more streams are being added to the native or trophy concept.

Let's have a look at what happens when a stream is placed under native or trophy regulations. On Lost Cove Creek when the stream was closed to bait fishing, the fishermen stayed away, fisherman trips dropped from a high of 612 to 175. The same thing happened to South Mills River, and the North Fork. Rather than expend 95% of our efforts in trying to manage the fishermen, isn't it time to start managing the trout and its habitat. Isn't it time to start doing something about the uncontrolled development that is destroying more habitat and fisheries in one year than millions of trout fishermen could ever destroy.

Think of this, when our mountain lands are listed on the tax books at the same value as business property, I think we will continue to lose more than just trout. I think it worth repeating, the sure way to exterminate a trout fishery is to destroy its habitat.

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REVIEW OF SELECTED PARAMETERS OF TROUT STREAM QUALITY

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Abstract.--Physical and chemical parameters important to the productivity of trout streams include temperature, dissolved oxygen, water clarity, and substrate characteristics. Temperature is the critical parameter; and maximum weekly average during the summer should not exceed 66°F, with short-term maximums for survival of 73° to 75°F for brook and rainbow trout respectively. For optimum production, oxygen should be maintained at natural levels. Potentially severe effects of turbidity and siltation require that every effort be made to keep mineral solids from reaching a watercourse.

High-quality, natural trout streams are characterized by low water temperature, high water transparency, high dissolved oxygen concentrations, and by sufficient accessible areas of clean, unsilted substrate to allow reproduction of native and/or introduced salmonid species.

Each of the above parameters may be readily altered by perturbations resulting from man's activities; and consequently, trout streams are among the most sensitive ecosystems with which resource managers and regulatory agencies must cope. Among the activities which may seriously disrupt trout streams may be included:

- Mining.
- Road Building.
- Deforestation.
- Channelization.
- Dam construction.
- Oxygen-demanding industrial and domestic wastes.
- Heated wastes from industry.
- Turbid wastes from industry.
- Dredging.
- Irrigation.

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In addition to their sensitivity, trout streams are relatively low in productivity (Needham 1939) and are limited in geographic location and total acreage. These factors combined with the high value of trout streams for esthetic, recreational, and economic reasons have resulted in special attention from state and federal agencies charged with the responsibility of managing natural resources and from regulatory agencies engaged in the control of water pollution.

Recent national water pollution control legislation of importance for the maintenance and restoration of trout-stream quality include the Water Quality Act of 1965 (Public Law 89-234) and the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500).

Public Law 89-234 provided for the classification of interstate waters for various uses, including propagation of fish and wildlife and for the establishment of standards of water quality for each use. In implementation of this act trout waters were singled out for particular attention in terms of dissolved oxygen and temperature. Unfortunately, many excellent trout streams are not interstate in extent and thus do not come under the terms of Public Law 89-234.

Public Law 92-500 marshalled in a new era of water pollution control with stated national goals, including that:

- The discharge of pollutants into navigable waters be eliminated by 1985.
- Wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983.

Navigable waters were broadly defined as "waters of the United States, including territorial seas;" and thus, essentially all inland streams were brought under the umbrella of this act.

The scope of this paper is limited to a discussion of the significance, for streams only, of natural levels, degradation and regulatory standards pertaining to selected parameters of importance in determining the quality and productivity of trout streams.

TEMPERATURE

Water temperature is the single most important environmental parameter determining the suitability of a stream for the propagation and maintenance of trout. Temperature limits the geographic distribution of streams suitable for trout to areas of the U. S. where cool summertime air temperatures, dense shade, snow melt, and input of cold subterranean waters from springs and underground rivers act singly or in combination to maintain suitable stream temperatures.

Needham (1969) reported the limiting high temperatures for brook, brown, and rainbow trout to be 75°F, 81°F, and 83°F respectively. These temperatures are near lethal levels, and streams having temperatures this high would be unlikely to support a self-sustaining trout population. As stated by Brett (1960), "a major requirement for a physical environmental factor like temperature is that it should provide for a level of activity commensurate with maintaining the species at a population level which is more than just a token sample." Temperature affects all metabolic and reproductive activities of fish including such critical functions as growth, swimming, and the ability to capture and assimilate food. Accordingly, optimum temperature requirements may vary, depending on season and life stage.

Based on an evaluation of available research USEPA (1973) provides recommendations as to maximum temperature for critical functions of rainbow trout and brook trout (Table 2). For long-term exposure (growth column) a temperature that is one-third of the range between the optimum growth temperature and the ultimate incipient lethal temperature was selected. Maxima for adult survival listed in Table 2 are based on the 24-hour median tolerance limit minus a 2°C (3.6°F) safety factor to assure no mortality. The maximum weekly average temperature should preferably be based on hourly readings from a constant recording device (168 data points per week).

Table 1.--Maximum weekly average temperature for growth and spawning and short-term maxima for survival of juveniles, adults, and embryos (centigrade and fahrenheit)^{a/}

	Rainbow Trout	Brook Trout
Juvenile and adult <u>growth</u> during summer	19 (66)	19 (66)
Short-term maxima for <u>survival</u> of juveniles and adults	24 (75)	23 (73)
Spawning	9 (48)	9 (48)
Short-term maxima for <u>embryo</u> survival	13 (55)	13 (55)

^{a/} From USEPA (1973).

Numerous activities may influence stream temperatures including deforestation from logging, fires, and agricultural practices; irrigation; groundwater overdraft; impoundment; and heated discharges from industry. The effects of various types and levels of deforestation (strip cutting, patch cutting, complete clearcutting, understory removal, etc.) on stream temperature have received wide attention, and studies in general have shown that extensive removal of riparian cover can seriously alter water temperature.

Burns (1972) found that a 140-percent increase in radiation from road construction beside a small California stream increased water temperatures by as much as 11.1°C. Greene (1950) reported that a stream draining a deforested basin

in western North Carolina had maximum temperatures 9 to 23°F higher than an adjacent forested stream. The average increase of the maximum was approximately 12°F. Greene further reported that the farm stream temperature decreased from 80° to 68°F (12°F) after meandering through approximately 400 feet of cover. Eschner and Larmoyeux (1963) reported an 8°F increase in temperature resulting from clearcut logging of a West Virginia watershed. These authors were of the opinion that the increases in stream temperature were the result of heating the entire watershed rather than the effect of direct insolation on the exposed water surface.

The most severe increases in temperature were reported by Brown and Krygier (1970) and USEPA (1971) for a stream draining a clearcut watershed of a small Oregon stream where increases in maximum temperature of 28°F were recorded. Higher temperatures persisted for 4 years, although regrowth resulted in a general decrease toward pre-logging levels in the latter years of study. The authors predicted that summer maxima would approach pre-logging levels after 6 years. These authors determined that the principal cause of high water temperature following logging is exposure of the stream to direct insolation, not increased soil temperature of the drainage basin as suggested by Eschner and Larmoyeux. Brown (1969) showed that net thermal radiation is the predominant source of energy for the stream, while evaporation and convection seem to play a minor role. Brown further found that substrate plays an important role in temperature relations of streams with solid rock serving as a significant energy sink and source (depending on time of day) while gravel bottoms seemed to be insignificant energy sinks.

Studies of heat loss from a thermally loaded stream showed that even in the shade, relatively small amounts of heat are added to the stream throughout the day; thus, it would be anticipated that the stream will not cool as it flows through a shaded reach but will continue to increase in temperature at a very slow rate (USEPA 1971). My studies of stream temperatures at Coweeta Experimental Forest during 1953 and 1954 showed that there was a continuous and gradual downstream increase in temperature in a 650-meter section of Shope Creek as it flowed through alternately cleared and forested areas and thus, confirms the conclusion of the USEPA report. These findings are in conflict with the data of Greene (1950) mentioned previously and those of Burns (1972), who found that downstream from a cut area on a California trout stream there was a one-half degree centigrade decrease in stream temperature for each 100 meters of uncut area. It appears quite likely that cooling by intermittent strips of stream cover is highly site-specific and dependent upon such factors as intensity of shade, air temperature in cleared versus shaded areas, substrate characteristics, and level of evaporative cooling as influenced by variable stream turbulence.

OXYGEN

Adequate dissolved oxygen is a necessity for the propagation and survival of trout and the instream organisms upon which they depend for food. Concentra-

tions of dissolved oxygen in water are dependent upon temperature, pressure, physical aeration, and the balance of photosynthetic and respiratory activities of resident plants and animals.

Because of cool water temperatures and high rates of aeration, most unpolluted trout streams maintain relatively high concentrations of dissolved oxygen. It has generally been shown that for optimum conduct of metabolic and reproductive activities, trout require high levels of dissolved oxygen; and for maximum protection designed to fully insure unimpaired productivity, Doudoroff and Shumway (1970), in a comprehensive summary of oxygen requirements of fishes, indicate that oxygen concentrations should not be reduced below levels naturally occurring during different periods of the year.

Deleterious alterations of dissolved oxygen in trout streams may result from impoundment, from inputs of decomposable organics, and from excess growths of aquatic plants. Reductions in dissolved oxygen below impoundments are well-known and result from withdrawals of water from deep deoxygenated layers of the impoundment during summer stratification or from interflows of deoxygenated water at depths coinciding with depths of the penstocks. Excess growths of aquatic plants may cause severe diel fluctuations in dissolved oxygen with daytime supersaturation and anoxic conditions during the night. Although severe effects of aquatic plant growths are certainly a potential problem, I am not aware of any trout stream studies where this phenomenon has been documented. The most common cause of oxygen depletion results from the discharge of oxygen-demanding organic wastes from agricultural, municipal, and industrial sources and such occurrences are well-documented in the literature. Logging slash has been reported by Burns (1972) to have reduced dissolved oxygen in a trout stream to 5 ppm, while undisturbed sections of the same stream had 10 ppm of dissolved oxygen. Hansmann and Phinney (1973) reported that logging slash in Oregon streams reduced oxygen concentrations from natural levels of 10 to 12 ppm to as low as 0.6 ppm.

TURBIDITY

Mineral solids may affect the quality and productivity of a trout stream by creating unsightly and damaging turbidity while in suspension and by the deposition of silt on the stream bottom. Excellent reviews of this general subject have been presented by Cordone and Kelley (1961) and by Gammon (1970).

The amount of sediment that can be transported in suspension by a stream is directly related to stream velocity and inversely related to the particle size of available sediments. Thus, unless influenced by continuous point discharges of sediments or by suspensoids of colloidal dimensions, most trout streams are quite clear during periods of low or normal streamflow. Measured turbidities of streams draining undisturbed forest lands have been reported to normally be less than 10 ppm (FWPCA 1970, Bartsch 1960, EPA 1971). In 1953 and 1954, I measured the turbidity of Ball and Shope Creeks on Coweeta Experimental Forest in North Carolina during six separate storm periods (Table 1). Turbidity of Ball Creek,

which drained a relatively undisturbed watershed, ranged from approximately 3 ppm to 43 ppm. In Shope Creek, whose drainage system included small watersheds that had been subjected to logging and farming operations in earlier years, the turbidity during storm periods ranged from approximately 31 ppm to 808 ppm. During periods of normal to low streamflow during 1953 and 1954, the turbidity of both Ball and Shope Creeks was generally less than 5 ppm.

Table 2.--Turbidity data during storm periods for Shope Creek and Ball Creek, Coweeta Experimental Forest

		Shope Creek		Ball Creek				Shope Creek		Ball Creek	
Date	Time	Turbidity		Turbidity		Date	Time	Turbidity		Turbidity	
1953		(ppm)		(ppm)		1954		(ppm)		(ppm)	
9-25	1000	46.2*		9.0*		2-20	1000	63.6		4.7	
11-22	1345	112.3		36.1		2-20	1115	31.0		3.2	
12-9	1115	35.4		16.7		2-20	1500	808.2		43.0	

*Represents the mean of three readings.

The effects of poorly planned land use practices on stream turbidities are often quite dramatic, particularly during storm periods in areas of steep terrain. Turbidities reported during storm periods in streams draining improperly logged watersheds have ranged from 3,500 to 70,000 ppm (FWPCA 1970, Liebermann and Hoover 1948). Continuous high levels of turbidity from point sources such as sand- and gravel-washing facilities and mining operations are considerably more detrimental to stream fauna (Gammon 1970) than are the effects of intermittent turbidity from erosion products during storm runoff.

Studies by Wallen (1951) showed that there were no directly observable effects of turbidity on fish until concentrations greater than 20,000 ppm were reached, and most individuals of all species studied endured exposures of 100,000 ppm for a week or longer. Since the above concentrations are greater than would be expected to occur in nature, it has generally been felt that the direct effects of turbidity on fish are negligible. Subsequent long-term studies by Herbert, *et al.* (1961a and 1961b) indicate that direct effects on trout may occur at much lower concentrations than reported by Wallen. In the studies reported by Herbert, *et al.* (1961a), fish were exposed to test concentrations of mineral suspended solids for periods of approximately 6 months. Survival was adversely affected by concentrations of 810 and 270 ppm, while 90 ppm appeared to have some adverse effects. Herbert, *et al.* (1961b) found 1,000 ppm of suspended solids from china clay workings markedly reduced the abundance of brown trout.

Indirect effects of turbidity are undoubtedly of more significance to stream quality and productivity than is the direct mortality of trout. Trout are sight feeders, and reductions in visibility from turbidity reduce the ability

of trout to locate food. Bachman (1958) found that cutthroat trout exposed to only 35 ppm of silt turbidity ceased to feed, while control fish fed actively throughout the study period. Numerous authors have noted that silt-induced turbidity reduced light penetration, with a concomitant reduction in primary production by instream plants (Ellis 1936, Chapman 1962, Bartsch 1960, Tarzwell 1957, Cordone and Kelley 1961). Corfitzen (1939) attributed lack of light penetration to the absence of algae in silt-laden canals. Cordone and Pennoyer (1960) found that an abundant population of algal pads of the genus Nostoc was virtually destroyed by sediment discharged into the Truckee River, California.

Most studies of macroinvertebrates have been directed toward the effects of siltation, and few workers have attempted to differentiate the effects due to turbidity from suspended particles. In a very interesting study of an Indiana stream, Gammon (1970) found that when more than 80 mg/l above background levels of inert solids were added to the stream, the population density of macroinvertebrates decreased to about 40 percent of normal. When 20 to 40 mg/l were present for a part of each day, the depression in population density was about 75 percent of normal. These studies further revealed an increase in drift rate of macroinvertebrates from riffles in direct proportion to the increase in suspended solids concentration up to about 160 mg/l.

Turbid streams have reduced esthetic appeal and, as indicated by creel census data from a highly turbid logged stream in western North Carolina, they support little fishermen use (Tebo 1956).

SILTATION

Characteristics of the substrate is of critical importance to the productivity of trout streams. The stream bottom is utilized for incubation and hatching of trout eggs, for development of trout fry, and is the residence of aquatic macroinvertebrates which serve as an important food source for trout and for other secondary and tertiary consumer species.

Numerous studies of the effects of silt on trout reproduction have been conducted (Peters 1965, Shumway 1960, Hobbs 1937, Shapovalov and Taft 1954, Wickett 1954, Cooper 1956, and others). The findings of these studies overwhelmingly indicate that sedimentation in gravel riffles seriously reduces the survival of trout embryos and fry. Peters (1965) stated:

"Continuous large sediment concentrations in a stream during the trout incubation period can determine the recruitment of young-of-the-year trout to the population. Without high yearly recruitment, the trout population can be replaced by a species whose needs are better supplied by the environment."

Most workers have judged that both water velocity and dissolved oxygen concentrations determine adequacy of the gravel environment for hatching and survival of salmonid embryos and fry. Increases in sedimentation sufficient to alter

gravel permeability reduces velocities and decreases intergravel dissolved oxygen. As pointed out by Doudoroff and Shumway (1970), it is impossible to separate the effects of lowered oxygen and reduced intergravel velocity in field experiments; and indeed, the smothering effect of silt deposited directly on developing eggs also confounds such experiments. Burns (1970) reviewed the subject of sediment particle size on survival and states that "survival is lower as the volume of materials less than 25 mm diameter increases." In studies on Deer Creek in Oregon, it was found that an increase of only 5 percent in material smaller than 0.8 mm caused a 19-percent decrease in emergence of silver salmon fry (Hall and Lantz 1969).

Although allochthonous inputs may provide as high as two-thirds of the primary energy source (organic matter) for streams (Chapman and Demory 1963, Nelson and Scott 1962), it has also been conclusively demonstrated that benthic macroinvertebrates are of critical importance in the diet of trout (Leonard 1948, Henry 1949, Allen 1951, Tarzwell 1938, Tebo and Hassler 1963), and a serious reduction in this component of the trout food supply would be detrimental.

Substrate characteristics of streams is one of the most important variables determining the composition and productivity of benthic macroinvertebrates (Smith and Moyle 1944, Weber 1973). Of the mineral substrates, rubble is reportedly most productive, with decreases in productivity as particle size decreases to the fineness of sand and silt (Sprules 1947, Smith and Moyle 1944, Tarzwell 1937). Organic sediments in pools are also high in productivity (Sprules 1947, Tarzwell 1938).

An extensive review of literature by Cordone and Kelley (1961) led to the conclusion that the deposition of silt can and often has destroyed insect and mussel populations. Studies by Tebo (1955 and 1957) in North Carolina streams showed that during periods of silt accumulation below a logged watershed, there were significant reductions in standing crops of bottom organisms and further that organisms inhabiting the unstable substrate in the silted area were subject to severe decimation by floodwaters. Bartsch (1960) reported that turbid waters from gold-dredging operations in Oregon streams decreased the density of fish food organisms to almost zero.

DISCUSSION

Trout streams are exceptionally sensitive aquatic systems requiring the maintenance of high standards of water purity. Parameters of critical importance in determining the productivity of trout streams and reviewed in this paper, include temperature, dissolved oxygen, water transparency, and physical nature of the substrate.

Water temperature is the key parameter and final determinant of whether a stream can or cannot support salmonids. Thus, if a stream is to be maintained for trout, there can be no compromise regarding activities which will increase temperatures above those necessary for maintenance and propagation of trout. Currently available evidence indicates that maximum average summertime tempera-

tures for trout-producing waters should be near 66°F, with maximum upper short-term limits below 73°F to 75°F.

Dissolved oxygen is of critical importance for trout-producing waters through its influence on physiological and reproductive activities of trout. Minimum levels of dissolved oxygen for survival of adult and fingerling salmonids is apparently near 2.0 ppm; however, much higher levels must be available to support a viable trout fishery and for optimum production, dissolved oxygen should be maintained at natural levels.

Water clarity and substrate are influenced by turbidity and associated siltation from mineral solids. Accordingly, both clarity and substrate are highly sensitive to alterations in the mantle of protective vegetation which maintains soil stability and integrity. Turbidity sufficient to appreciably reduce water clarity impairs the esthetic and recreational value of trout streams; may cause trout mortality from gill clogging and abrasive effects; reduces instream production by plants; and may directly reduce the production of invertebrates which serve as an important food source for trout.

Silt settling on a stream bed fills the productive interstices in gravel and rubble riffles, making them unsuitable for fish spawning and for production of food organisms; it blankets productive deposits of organic matter in pools, and deep pools which provide cover and living space for trout may be completely obliterated.

Because of their recognized value, trout streams have received special consideration from regulatory agencies involved in the control of water pollution. A check of the water quality standards of three southeastern states and three western states reveals that stringent standards have been promulgated for dissolved oxygen, temperature, and turbidity in trout waters (Table 3).

Table 3.--Water quality standards for trout waters in three southeastern states and three western states

State	Dissolved Oxygen (mg/l)	Temperature	Turbidity
NC	6.0 ^{1/}	68°F ^{2/} maximum - No increase over ambient permitted	No limit specified
GA	5.0	No change permitted	No limit specified
TN	6.0	68°F maximum - 5.4°F over ambient	None harmful to fish life
CO	6.0	68°F maximum - 2°F over background	10 Jackson units over background
MT	7.0	68°F maximum - 2°F over background	5 Jackson units over background
WY	6.0	68°F maximum - 2°F over background; no increase over spawning beds	10 Jackson units over background

^{1/} 5.0 mg/l for put-and-take trout waters.

^{2/} 70°F maximum with 3°F increase for put-and-take waters.

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FOREST MANAGEMENT IMPACTS ON COLD WATER FISHERIES

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Abstract.--Erosion is the mechanism likely to damage the aquatic resource when a forest is managed. Roads, logging, site preparation, and fire all increase erosion and stream siltation. Cutting forests increases streamflow when it is needed most, but conversion from hardwood to pine significantly reduces streamflow and, therefore, the size of the aquatic habitat. Herbicides and pesticides are constant threats, but pollution from these sources can usually be prevented. More research is needed to fully assess the effects on the aquatic community of logging debris in streams, channel clearing, increasing stream temperature from logging along the stream, and changing the nutrient budget of streams by fertilization or silvicultural practices.

Additional keywords: Forest management, aquatic environment, trout, soil erosion, erosion control, sediment control, hydrologic properties, forest burning, forest soils, water yield, fertilization.

An undisturbed forest produces water of relatively high quality. Any disturbance to the forest through use or management affects the system, and water is one of the first characteristics to be affected. Alteration of cover density or type changes the volume, timing, and quality of flow, and one of the greatest changes is to the quality of water. Turbidity is the most obviously affected. Turbidity, for example, has been shown to increase by 4,000 to 5,000 fold following logging where roads were "logger's choice" compared with an undisturbed forest (Reinhart, et al., 1963).

Dr. Tebo (this symposium) has already presented information on the biological consequences of sediment and some other pollutants on the aquatic environment. We shall deal specifically with the importance of forestry operations on streams and how careful planning and execution can minimize the potentially harmful effects of management.

EROSION AND ITS CAUSE

Erosion takes place when energy available for detachment and transportation of soil exceeds the energy which binds soil particles in place. In the East, the major source of erosive energy is rainfall. Transportation of dislodged soil particles is also primarily by either falling rain or water flowing over the surface of the soil.

Raindrops reach a maximum diameter of only about 5 mm, but they strike exposed soil like tiny bombs; they "explode," digging craters and blasting soil into surrounding areas. An inch of moderately intense rainfall delivers over 1,000 times more potential energy for erosion than an equivalent volume of water flowing uniformly over the soil surface.

Overland flow is both an eroding force and a transporting medium for dislodged soil particles. As velocity of flow increases, energy available for erosion increases exponentially. The weight of soil which can be carried and the size of the particle which can be moved are increased by the 5th and 6th power of velocity.

Erosion is proportional to both length and steepness of slope. Little or nothing can be done about these factors on forest land, and silvicultural practices may have to be modified on steep, long slopes. On man-made structures such as roads, length and steepness of slope can be controlled.

Physical properties of soils determine their erodibility and influence stream turbidity (Middleton, 1930; Anderson, 1954). Indices of erosion hazard have been developed by the Soil Conservation Service for all southern soils.

Cover conditions and conservation practices exert the greatest influence on erosion. Wischmeier and Smith (1965), who prepared a universal equation for estimating soil loss from agricultural lands, demonstrated that man's management and conservation practices are more important in determining soil loss than all other factors combined.

In the forest, the litter layer is the most important mechanism for soil conservation. A 2-inch depth of litter (about 2 tons per acre) is sufficient to minimize erosion on forest lands (Wischmeier, in press; Rowe, 1955). Litter serves two very important functions. First, it absorbs the erosion energy of raindrops. Secondly, as litter decomposes and is incorporated into mineral soil, soil density is reduced, porosity is increased, and infiltration rates of about 20 to over 100 inches per hour are common. Since rain nearly always falls at rates of less than 8 inches per hour, virtually all rainfall infiltrates into forest soils, and surface runoff from upland forest soils is rare. Consequently, annual soil losses are small, normally less than 150 pounds per acre from undisturbed forests and not much greater from depleted hardwoods or pine plantations growing on eroded soil (Ursic, 1963; Ursic and Duffy, 1972; Rogerson, 1971). In the Blue Ridge Mountains, losses are normally less than 100 pounds per acre (Douglass and Swank, 1974) and less than 250 pounds from a clearcut watershed and a grass-to-forest successional forest (Johnson and Swank, 1973). Although expressed on a per-acre basis, much of the soil loss from undisturbed forests is normal geologic erosion from the micro- and macro-drainage network rather than accelerated erosion.

FORESTRY OPERATIONS WHICH INCREASE SILTING OF STREAMS

From this discussion of erosion, it becomes clear that any activity which reduces energy absorption by the litter and allows raindrops to strike mineral soil will increase erosion and stream siltation. Similarly, any activity which compacts soil or reduces porosity will lower the infiltration rate. If infiltration is reduced and surface runoff occurs, increased erosion is a virtual certainty.

Roads

One of the most damaging aspects of forest management is erosion from roads. Megahan (1972) found that soil loss from roads was 220 times greater than from undisturbed forests. Turbidities as high as 56,000 ppm have been reported for "logger's choice" roads in West Virginia (Reinhart et al., 1963), and Packer (1967) reported that roads are the major source of increased turbidities during forest operations.

Figure 1 shows the annual cycle of stream turbidities at Coweeta for an undisturbed and a logged watershed where roads were logger's choice. Although the values shown are instantaneous and depend partly on whether samples were

taken during storm or nonstorm periods, the general trend is unmistakable. Turbidity from the logged watershed is consistently higher in both storm and nonstorm periods.

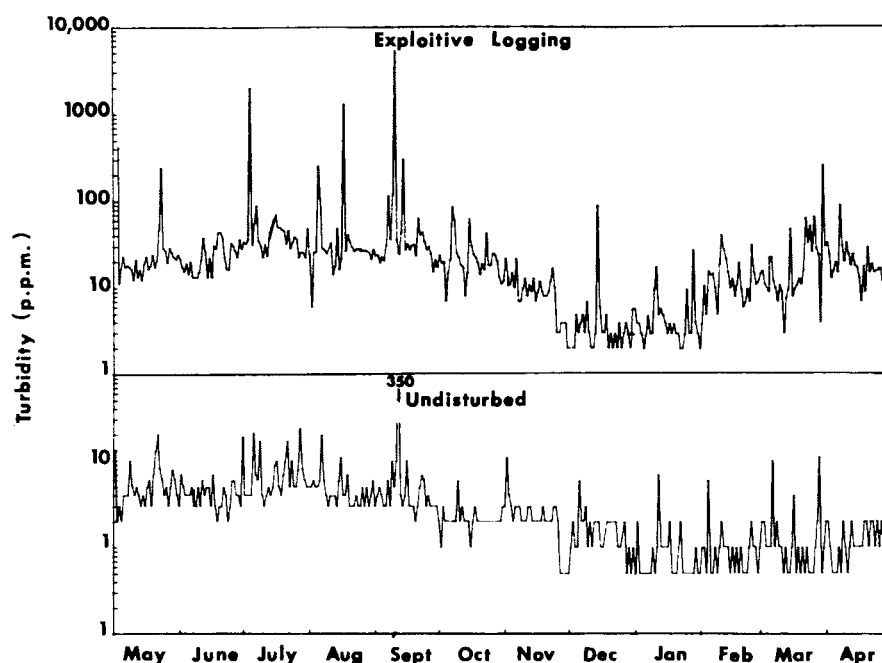


Figure 1.--Comparison of stream turbidity on an undisturbed watershed and an exploitively logged watershed.

Douglass and Swank (1974), Lieberman and Hoover (1948), Hoover (1945), and Reinhart et al. (1963) all reported that poorly constructed logging roads are a major cause of high soil losses and stream siltation. However, erosion and stream siltation can be held within reasonable bounds if roads are properly located, properly maintained, and properly stabilized. Since the road surface and unstabilized cuts and fills receive the energy of falling raindrops and running water, careful attention should be given to grades, length of slope, and drainage of accumulations of water. While all soil loss from roads cannot be eliminated, we have road construction and maintenance criteria which will maintain a healthy aquatic community (Hewlett and Douglass, 1958; Kochenderfer, 1970).

Logging

Improper logging can be a major source of erosion. Although erosion data associated with logging in the East are not available, evidence indicates that erosion loss is proportional to the area disturbed by exposure of mineral soil or compaction. The area disturbed varies with sale layout and design, supervision provided during the sale, and the logging equipment used to harvest the timber.

Timber sale design and layout can greatly minimize erosion by minimizing road, skid trail, and logging deck disturbance. Careful layout of logging roads well away from streams, requiring no blading off of mineral soil on skid

trails, no crossing of streams except on roads, and setting gradient limits for off-road use of wheeled and track vehicles are other measures which reduce disturbance.

The best sale design and layout, however, are of little value if supervision is inadequate and provisions of the contract are not enforced. Hatchell et al. (1970) showed that the area disturbed ranged from 3.2 to 22.8 percent for primary skid trails, 8.8 to 42 percent for secondary skid trails, and 0.3 to 4.6 percent for log decks in the Coastal Plains. Obviously, sale layout, supervision, or both were responsible for the 5- to 10-fold difference in disturbance during logging.

The logging equipment used determines to some extent the degree of disturbance during logging. Dickerson (1968) found that clearcutting sawtimber in the Coastal Plains disturbed 50 percent more soil and clearcutting pulpwood disturbed 50 percent less soil than selection cutting. He found no appreciable difference in total area disturbed by log-length skidding by mule, A-frame, or crawler tractor but skidding with rubber-tired tractor disturbed the most (17%) area.

In the West, Dyrness (1972) found that soil compaction varied: Tractor > high lead > skyline > balloon. He also found that tractor logging disturbed more area than high-lead logging (1965). Klock (1973) found cable skidding > tractor skidding on bare soil > tractor skidding on snow > helicopter logging. Meyer et al. (1966) found that articulated rubber-tired skidders caused greater damage than crawler tractors, particularly when skidding tree-length logs. Fredrikson (1970) found sediment losses of 0.15 tons per acre from undisturbed forests compared to 0.48 tons per acre after skyline logging with no roads. About 4 tons per acre were lost from high-lead logging by clearcutting where 25 percent of the area was cut in patches and 1.65 miles of road were used. Although not collected on southern Appalachian soils, these data probably illustrate range of disturbance by different logging equipment and operators in any area.

Erosion loss attributable to felling and skidding per se is slight. Dissmeyer (1973) estimates that logging produced only 0.6 percent of the forestry related sediment production in the Santee River Basin. The remainder came from fire, skid trails, spur roads, landings, and mechanical site preparation. This small percentage can probably be reduced further by careful planning, supervision, and use of proper equipment and methods.

Site Preparation

Forecasts indicate that 30 million southern acres require planting or conversion from low-grade hardwoods to pine if our future timber needs are to be met. Heavy equipment (and perhaps fire) will be used extensively to prepare many sites for planting. This preparation bares mineral soil to the erosive force of falling rain and flowing water. Preparation with heavy equipment closely approximates agricultural practices and has the greatest potential for increasing erosion and stream siltation of any forestry practice. Dissmeyer (1973) estimates that 81 percent of the forestry-related erosion in the Santee River Basin is caused by site-preparation work. There are no quantitative data on soil losses associated with alternative site-preparation methods which might achieve the desired conditions while causing less erosion. Additional research on this subject is badly needed because of the potential damage to the soil, water, and aquatic resource.

Fire

The results from prescribed burning studies are variable. Some indicate that erosion is not increased and physical properties which affect infiltration are not adversely affected. However, fire bares soil to raindrop and crown drop. Copley et al. (1946) found that annual burning of second-growth hardwoods for 7 years caused erosion to increase from about 200 pounds per acre to 28.7 tons per acre per year. Prescribed burning and deadening hardwoods increased erosion in Mississippi (Ursic, 1970). Soil loss increased by 48 to 119 percent, but the maximum increase was less than 500 pounds per acre. Thus, it appears that prescribed burning may increase soil losses, but periodic prescribed burning of woodlands does not appear to be a threat to aquatic life in the mountains. Annual burning, however, can result in excessive erosion, stream siltation, and damage to trout.

FOREST MANAGEMENT CHANGES STREAMFLOW

A wealth of information is available to show that changes in forest cover conditions affect both the timing of flow and total annual flow. Douglass and Swank (1972; 1974) presented models for estimating the magnitude and duration of yield increases when hardwood forests are cut. On an annual basis, complete clearcutting of Appalachian hardwood forests will increase streamflow by from 8 to 18 area inches the first year after cutting; when hardwood forests are cut on a sustained-yield basis, annual flow will be about 0.5 to 2.5 inches greater than from an unmanaged or wilderness forest.

Changes in flow distribution are more important to the aquatic community than total flow. Figure 2 shows the average change in monthly flow for 7 years when a hardwood-covered watershed was clearcut annually. Flow was approximately doubled during late summer, fall, and early winter, when it is normally low. Low flows can cause stress for trout, and increases in minimum flows may be of great value.

Figure 3 compares the average monthly flow for a hardwood forest and the flow which occurred 16 years after this watershed was converted to a white pine plantation. The reduction in flow was attributed to greater interception and transpiration by the pine. Streamflow was reduced by over 8 inches annually. The greatest reduction in flow came during December through May, but reductions occurred in all months. Although small, the reductions during July through November are important because they occur when the trout population may be under stress.

From these and numerous other watershed studies, it is clear that manipulating forest cover in the Appalachians strongly influence streamflow and, therefore, the aquatic community. Hardwood management can increase the amount of water in streams thus enlarging the aquatic habitat. The largest increase comes the year after cutting, and increases diminish with time. Small increases in flow will occur on larger streams where sustained-yield management is practiced, and this additional water comes mostly during the period when the physical habitat is minimal. On the other hand, conversion of hardwood to pine will reduce flow after the pine has reached about 10 years of age. Thereafter, flow will probably remain significantly lower in all months until the pine forest is regenerated. This reduction will almost certainly have a negative effect on the aquatic resource, particularly if substantial portions of the watershed area are converted.

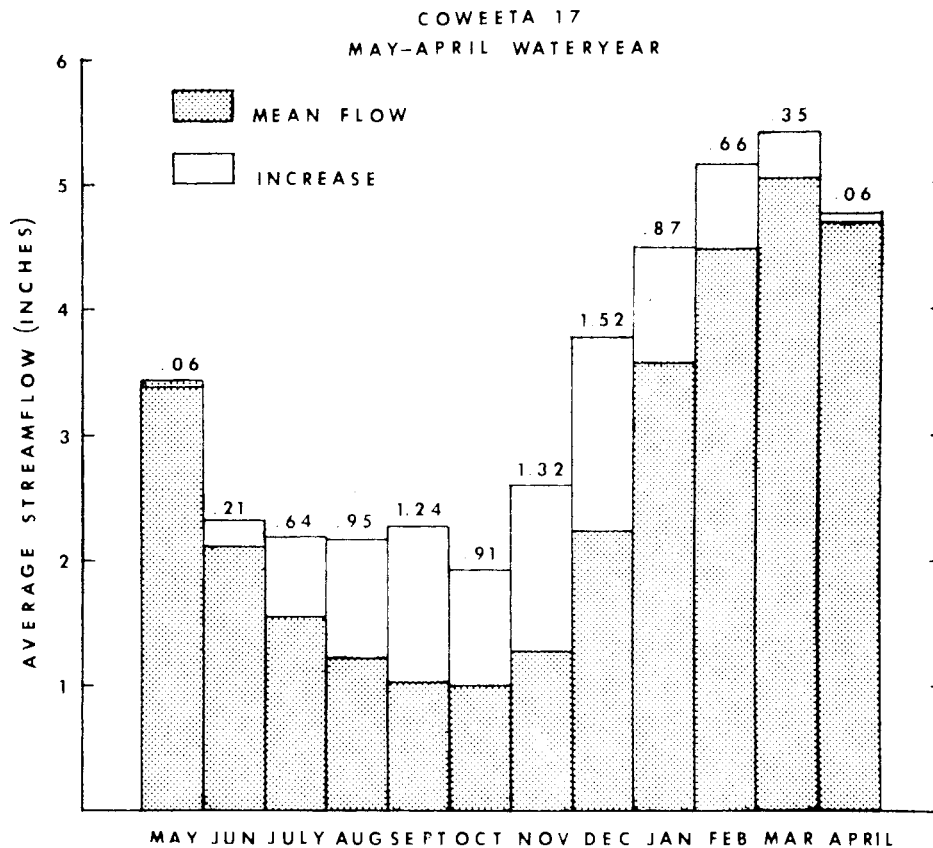


Figure 2.--Comparison of the mean monthly flow from a hard-wood-covered watershed with the average increase in stream-flow during a 7-year period when that watershed was clearcut annually.

OTHER MANAGEMENT EFFECTS

Streamside Cuttings

Water temperature is a limiting factor in both the geographical distribution and local occurrence of trout. If temperatures are not within the optimum range and trout cannot move to a more favorable habitat, the population is stressed. Certain forest management practices can increase water temperature in streams.

Swift and Messer (1971) compared water temperature in streams draining undisturbed watersheds with those subjected to treatments which ranged from mountain farming to understory cuts. Opening streams to direct sunlight raised both winter and summer weekly maximum temperatures. Summer maximums were increased up to 12° F by clearing the forest and farming the land. The maximum weekly temperature increased 5 to 6 degrees after a complete clearcut. Summer weekly maximums declined somewhat as a coppice forest regrew.

Hassler and Tebo (1958) found little change in temperature from clear-cutting streamside vegetation along a third-order stream at Coweeta. Swift and Baker (1973) studied temperature changes inside clearcut and streamside shade

strips on a commercially logged area near Asheville, N. C. Temperatures increased from 52° to 66° F in the clearcut. As the water flowed through an 800-foot thinned buffer strip, a 200-foot clearcut, and another 900-foot buffer strip, temperature declined to 57° F. After flowing through 700 feet of uncut forest, the temperature dropped to 55° F. The study confirmed that a narrow buffer strip of uncut trees or shrubs along streams does moderate those increases in water temperature which might otherwise be caused by a forest cutting.

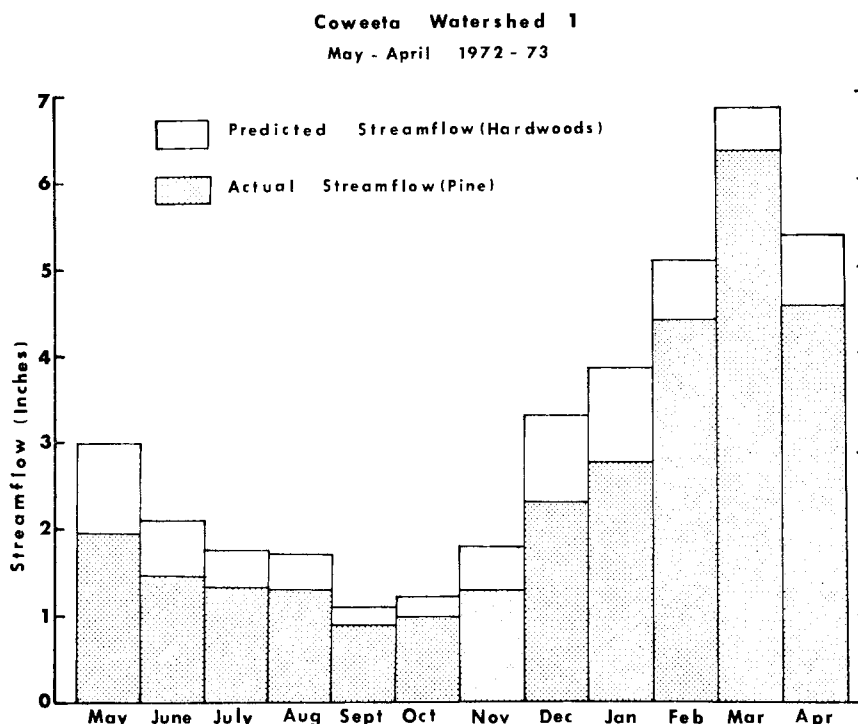


Figure 3.--Comparison of predicted streamflow by months for a hardwood watershed with actual streamflow when that watershed supported a 16-year-old white pine plantation.

While potentially harmful temperatures can result from removal of stream-side vegetation, such occurrences should be rare. On Forest Service lands, clearcutting are normally smaller than 50 acres and frequently along streams too small to support trout. Even though stream temperature may increase within the cut area, when this water mixes with cooler water from uncut areas or with inflow along the stream below the cutting, the increase is very quickly dissipated by dilution. In the water-influence zone of larger streams, cutting practices are modified to provide shade. Even on private land where cutting size is not rigorously controlled, the very small proportion of the total forest area which is likely to be clearcut at one time tends to prevent acute thermal pollution problems.

There are exceptions. We do not, for example, have data on what length of stream has to be cut before heating of water becomes a serious problem. A 390- to 750-foot clearing does not appear to create excessive temperatures, but cutting 1,000 or more feet along streams might cause excessive temperature increases. Cutting extensive areas of swamps where large volumes of water are in storage could also raise stream temperature dangerously. Water temperature naturally increases as elevation decreases. While some increases in temperature can be tolerated at higher elevations, at lower elevations where summer maximums are already at critical levels, no temperature increase can be tolerated.

Not all effects of opening up the channel are adverse. Some increase in temperature may be beneficial. The increase in temperature and greater lighting of unshaded streams may stimulate photosynthetic activity. Hassler and Tebo (1958) found that a 390-foot cleared stretch of stream at Coweeta generally contained a greater volume of invertebrates per sample than a wooded stretch of the stream. Although untested, limited clearing along streams offers potential as a management tool for increasing trout food production.

Wallace et al. (1970) found that stonefly nymphs (*Peltoperla maria*) showed definite feeding preferences for elm, alder, sourwood, and dogwood over rhododendron, white pine, white oak, and chestnut oak leaves. Since leaf material is one of the most important food sources for invertebrates (Minshall, 1967), manipulation of terrestrial plant cover adjacent to streams by complete or selective cutting may provide opportunities for improving the quality of food available to the aquatic community.

Effects of Cutting on Nutrient Budget

Since the initial reporting of high nutrient losses from a clearcutting followed by 3 successive years of herbicide treatment in New Hampshire (Likens et al., 1970), fear has been expressed that clearcutting reduces site productivity. Also, the higher-than-normal nutrient concentrations are pollution by some definitions, and the nitrate concentrations at times exceeded drinking water standards. At Coweeta, detailed nutrient balance studies on four watersheds (undisturbed forest, grass-to-hardwood successional forest, young white pine plantation, and a regrowing coppice forest; Johnson and Swank, 1973) and on other watersheds subjected to a variety of forest-cutting practices have not shown appreciable changes in the ion budget, except for nitrates (Douglass and Swank, 1974). Annual concentrations of $\text{NO}_3^- - \text{N}$ were increased by factors of four to 150, the highest concentration being 1.23 ppm for the grass-to-forest successional forest. This forest watershed has been limed, fertilized twice, and the grass was killed for 2 successive years with herbicides prior to the grass-to-hardwood succession study. Studies at the Bent Creek Experimental Forest confirm the findings at Coweeta that, except for nitrates, forest cuttings have little effect on stream nutrient concentrations.

Streams in undisturbed forests in the Blue Ridge Mountains are normally low in nutrients. Nitrate concentrations at Coweeta, for example, normally range from .002 to .013 ppm. Because of the low fertility of streams, increases in calcium, phosphate, nitrates, and potassium might improve the productivity of aquatic habitat. Only nitrates seem to be increased by forest cuttings, and these small increases in nitrates may not be sufficient to produce a favorable response in the aquatic community.

Fertilization

Fertilizer is being used increasingly in forestry to improve the growth of trees. Hilmon and Douglass (1968) and Hornbeck and Pierce (1973) concluded that fertilization may stimulate water use by forest vegetation. Hornbeck and Pierce point out that direct application of fertilizer to the stream channel and an increase in nutrients contributed to the stream by subsurface flow might affect water quality. This, in turn, could produce changes in aquatic life.

Aubertin et al. (1973) measured nutrients in streamflow from a West Virginia watershed before and after application of 500 pounds per acre of urea, about 11 pounds of which fell directly into the stream. Nitrate-N and ammonium-N concentrations increased immediately after application of the urea. Compared to the year before fertilization, there was a 10-fold increase in NO_3^- - N vs. approximately a 50-percent reduction in ammonium in streamflow during the year after fertilization. If one considered the increased loss of N as coming entirely from the urea fertilization, then 17.8 percent of the applied N was discharged during the first year after treatment. Although not wholly attributable to the urea fertilization, increases in concentration of Ca, Mg, K, Cu, Zn, and decreases in Fe, total phosphate, and Mn were noted. The NO_3^- - N concentration at times exceeded Public Health drinking water standards. Since NO_3^- - N readily leaches from soils, nitrate and urea are the fertilizers most likely to affect water quality.

N and P are of particular concern to limnologists. Werner (1973) points out that minerals are cycled through plant tissue and introduced to the stream as leaf detritus or from leaching through soil. His main concern was eutrophication, as commonly happens following agricultural applications of fertilizer. While eutrophication is a potential problem, a large percentage of the applied fertilizer is retained in the upper few inches of soil. For example, Sopper and Sagmuller (1966) found that 2 inches per week of sewage effluent applied at the equivalent of 2,500 pounds per acre of 10-10-10 fertilizer was largely retained in the surface foot of soil. Later applications of 4 inches per week showed that greatest changes in concentration of P and K percolate occurred in the surface foot, and NO_3^- - N, Ca, Mg, and chloride concentrations equilibrated at 48 inches (Pennypacker et al., 1967). Because of this filtering action, only a small percentage of the applied fertilizer should reach streams from leaching. If enrichment is not excessive, some enrichment may stimulate primary productivity in our low fertility streams. Also, fertilizer-enriched leaf detritus might increase invertebrate populations. Additional study of the effects of forest fertilization on the aquatic community is planned.

Pollution from Herbicides and Pesticides

Herbicides are sometimes used to control vegetation on road, powerline and other right-of-ways, and in site preparation and timber stand improvement activities. They are also used to increase productivity in the aquatic food chain, but if present in sufficient concentrations, they are toxic to fish. The toxicity of different herbicides is variable; death occurring within 48 hours from concentrations ranging from 0.13 to 4,800 ppm depending on the formulation (Alabaster, 1969). Because herbicides operate on both the food chain and the fish themselves (Walker, 1971; 1972), efforts should be made to use the least toxic chemicals to nontarget organisms in forestry operations. Norris (1971) concludes that commonly used brush control chemicals can be used with minimum hazard to the environment.

Pesticides are designed to kill, and numerous examples of fish kills and other aquatic problems are attributable to pesticides. However, the bulk of evidence indicates that herbicide and pesticide pollution can be reduced or eliminated by careful woods operations. At Coweeta, for example, maintaining an unsprayed 10-foot buffer strip along the stream was sufficient to prevent atrazine and 2,4,5-T from reaching streams; Grzenda et al. (1964) found that DDT residues appeared in streams at Coweeta after spraying the entire basin for elm spanworm by fixed-wing aircraft. The following year, DDT was carefully applied by helicopter to upper slopes, and ridges and residues were not found in stream or sediment samples. Since most pesticides reach streams either attached to soil particles, from spray deposited in streams, or from drip from exposed plant material, a cardinal rule is to avoid spraying stream-side areas. Because a wide variety of chemical compounds exist, use of rapidly degradable rather than persistent pesticides and herbicides can reduce both the initial hazard and the duration of hazard.

Logging Debris and Channel Cleaning

Logging debris that falls into streams can create barriers to fish movement, cause unproductive sediment bars, and accelerated channel and bank cutting. It is virtually impossible to prevent some debris from entering stream channels during logging. When the quantity or size of detritus becomes excessive or when flow during storms is sufficient to cause debris jams or excessive bank cutting, debris should be removed. This is a judgmental decision, but generally, flow volume in the southern Appalachians is not sufficient to move logs in streams draining 50- to 100-acre watersheds. If debris is left in streams, it becomes an important and long-lasting food source for invertebrates. Additional study is needed to evaluate the overall effects of leaving detritus in small feeder streams.

On National Forests, channels are cleared of old logging slash, blowdowns, old logs, and other debris. The practice can increase trout populations in certain situations but, like any management practice, it may be beneficial or detrimental. Productivity of the aquatic system can be improved by selectively removing barriers to fish movement and sediment bars while retaining debris which provides necessary cover. Carried to extremes, the practice can destroy productive gravel beds and eliminate fish cover. Guidelines have been developed for National Forest channel-cleaning work, but the effects of clearing debris on the aquatic community is another practice which has not been evaluated quantitatively.

CONCLUSION

Hydrology research in the Appalachians has defined many of the impacts of forest management practices on the water resource. For the most part, the information needed to protect the trout resource is available. However, the aquatic community is highly complex, and we do not know how some practices affect the food chain and ultimately the productivity of the trout resource. The ultimate objective of the research program in cold water fisheries is to develop the ability to predict how man's use of the forest will influence the trout resource and how the productivity of trout can be protected and enhanced.

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MINING IMPACTS ON TROUT HABITAT

Ronald D. Hill^{1/}

Abstract.---Mining by its very nature is a destructive process. Environmental damages from mining such as sediment, acid mine drainage, and heavy metals are discussed in terms of their effect on trout habitat and their control. Pollution control must be considered during all phases of mining, i.e., pre-mining planning, active mining, closure, and abandonment.

Additional keywords: Acid mine drainage, heavy metals, sediment, surface mines, underground mines.

INTRODUCTION

Mining is an extraction process. The disruption of the earth's surface and subsurface to remove the mineral wealth entombed therein, dictates that changes and possible damages will result to the environment. A certain price in environmental damage usually must be paid to obtain the minerals and energy required for our standard of living. The basic questions facing us are: (1) What is the price we must pay? (2) Can this price be reduced or eliminated? and (3) In what form do we desire to pay this price, i.e., loss of land values, recreational opportunities and fish, or higher prices for our commodities and energy? None of these questions are easy and the answers will vary from situation to situation. The only rational answer is to optimize both short-term and long-term costs and benefits to society. We must have mining if we are to survive, but this does not mean we must sacrifice the environment. Mining must be conducted in such a manner that environmental damages are held to a minimum.

The U. S. Bureau of Mines reported (Paone 1974) that the land utilized by the mining industry from 1930 through 1971 amounted to 3.65 million acres or 0.16 percent of the land mass of the United States. Land was utilized for surface mining, wastes from underground and surface mining, and wastes from mill operations. Some land was also lost to subsidence. The following figures were presented for land utilization by commodity over the 1930-71 period and 1971 alone.

These figures show that 58 percent of the land utilized is by the coal and sand-gravel industries. The following discussion on the impact of mining on trout habitat will cover the major sources of pollution from mining, and will emphasize the coal and sand-gravel industries.

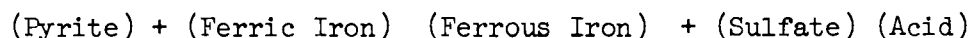
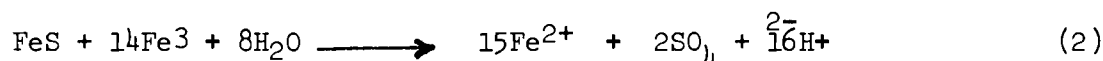
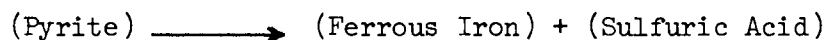
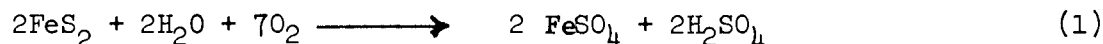
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	1930-71 <u>Acres</u>	1971 <u>Acres</u>
Bituminous Coal	1,470,000	73,200
Sand and Gravel	660,000	46,400
Stone	516,000	25,000
Clay	167,000	7,460
Copper	166,000	19,100
Iron Ore	108,000	8,620
Phosphate Rock	77,300	10,200
All Other Minerals	493,000	16,400

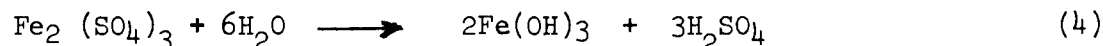
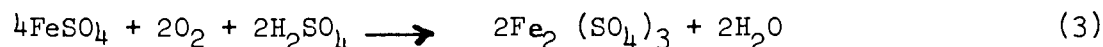
WATER PROBLEMS ASSOCIATED WITH MINING

Acid Mine Drainage

One of the most troublesome mine drainage problems is caused by acidity. Although the exact mechanism of acid mine drainage formation is not fully understood, it is generally believed that pyrite (FeS_2), which is usually associated with coal and heavy metal mining, is oxidized by oxygen (equation 1) or ferric iron (equation 2) to produce ferrous sulfate and sulfuric acid.



The reactions may proceed to form ferric hydroxide and more acid:



A low pH water is produced (pH 2-4.5). At these pH levels, the heavy metals such as iron, calcium, magnesium, manganese, copper, and zinc are more soluble and enter into the solution to further pollute the water. A list of common pollutants found in acid mine drainage follows:

<u>Pollutant</u>	<u>Range of Concentration</u>
pH	1.5 - 6.5
Acidity	50 - 50,000 mg/l
Sulfate	50 - 50,000 mg/l

Iron	10 - 5,000 mg/l
Al	0 - 200 mg/l
Mn	0 - 100 mg/l
Cu	0 - 500 mg/l
Zn	0 - 400 mg/l
Ca	50 - 3000 mg/l
Mg	10 - 1000 mg/l
Cd	0 - 10 mg/l
Na	0 - 5000 mg/l
Ti	0 - 100 mg/l

Other heavy metals are occasionally found in acid mine drainage.

The above pollutants can harm trout habitat by several means including immediate or long-term toxicity to fish, inhibition of fish reproduction, (notably spawning and fish egg and larvae survival), and reduce or destroy the availability of fish food fauna. It is beyond the scope of this paper to discuss each of the pollutants and its toxicity limits, conditions, etc. The reader is referred to a U. S. Environmental Protection Agency publication by Kemp (1973).

An estimated 10,000 miles of streams have been degraded by acid mine discharges in Appalachia (Appalachian Regional Commission, 1969). Additional acid problems have been documented in all of the coal and mineral producing states.

Alkaline Mine Drainage

Alkaline mine drainage may result where no acid-producing material is associated with the mineral seam or where in situ neutralization of that acid which is produced has taken place. Alkaline mine drainage may be, but is not usually, as bad as acid mine drainage. Drainage from freshly exposed strata usually has a higher mineral content than that from undisturbed land because the strata has high levels of readily leachable materials.

Curtis (1972) reported that he found the concentration of Ca, Mg, Al, SO_4 , Fe, Mn, and Zn increased in three eastern Kentucky watersheds when surface mining occurred. The water had an alkaline pH.

Some alkaline waters have high concentrations of ferrous iron and, upon oxidation and hydrolysis, form acid which lowers the pH and changes the drainage to the acid type. These types of discharges are more common to underground mines than surface mines.

The western coal mines present new problems. In many areas the overburden material is highly alkaline and sometimes saline (Hodder 1973). Documentation of the alkaline and saline problem is almost non-existent.

Sedimentation and Erosion

The removal of the vegetation and the loosening and breaking up of the overburden by blasting, shovels, draglines, and dozers creates materials and conditions conducive to erosion. Curtis (1969) and Collier (1966) have documented the increased sediment and suspended solid from surface mine areas. Mine waste piles, haulroads, tailings ponds, coal and ore stockpiles, and beneficiation plants are all sources of sediment. Collier (1966) showed that a partially stripped watershed (6.4 percent of area) had an erosion rate of 5.9 tons per acre per year as compared to 0.7 tons per acre for an unmined area. While conducting a study on the environmental effects of the sand and gravel industry, Newport (1974) made a review of the effects of sediment on benthic communities, planktonic communities, fish population, fish reproduction, and fish species composition. He concluded that sediment had a major impact on fish. Although he concluded that a precise minimum concentration of inorganic solids for good fisheries had not been unequivocally established, the following were meaningful approximations:

0 - 25	No harmful effects of fisheries
25 - 100	Good to moderate fisheries
100 - 400	Unlikely to support good fisheries
400 - above	Poor fisheries

Several states will not allow the suspended solids to increase more than 10 mg/l in streams classified for trout.

Erosion is influenced by the soil type (sand, clay, salt, infiltration rate, and percolation rate); the climate (temperature and amount and type of rainfall); the topography (steepness, length of slope, land configuration and exposure); and the vegetation cover. Each of these factors should be considered in the planning, development, and reclamation of a surface mine to prevent erosion.

SOURCES OF MINE DRAINAGE

Surface Mines

Surface mines fall into two broad types: area and contour. Area surface mining is practiced on relatively flat terrain and usually encompasses a large tract of land, up to several hundred or more acres. Area surface mining can be found mainly in Ohio, Western Kentucky, Illinois, Indiana, and west of the Mississippi River. Contour mining is practiced on rolling to very steep terrain. Usually only a few cuts are made into the hillside and the coal seam is followed along the edge of the hill or mountain, leaving a trace which appears as a "contour line."

In general, the pollution from area mines is not as severe as that from contour mines. During area mining, overburden can be more easily segregated and the acid producing or saline material more easily buried. Silt from erosion can often be confined to the mining area. The overburden can be graded to a slope that is less erosive. Final cuts can be filled with water to prevent oxidation of the pyrite material. Areas that have been area shown have been shown to have lower peak flows and increased base flows. (Grubb 1972) (Corbett 1965).

The common practice in the past was the placement of the overburden from a contour mine onto the downslope of the adjacent area. This material was subject to severe erosion and landslides. Plass (1967) made a survey of eastern Kentucky and found that 12 percent of the outslope area had failed (landslides). Because of the landslide problem, West Virginia has limited the bench width on steep slopes greater than 65 percent. Even with these precautions, landslides still occur. Many water problems arise from contour mining. Because of their long, bare, steep uninterrupted slopes, the highwalls and spoil piles are subject to severe erosion. Sediment coming off these slopes has been known to clog stream channels; cover highways; settle on cultivated land and kill crops; cover fish spawning beds; fill water courses and thereby subject adjacent land to flooding.

Even when spoil piles are graded, problems occur. If the grading is toward the highwall, the water may accumulate in an area of poor quality spoil (i.e., a spoil high in pyritic material) and may, therefore, be degraded in quality. Where underground mines are located behind the highwalls, grading toward it often causes water to flow into the underground mine. This flow often flushes toxic material from the mine.

When spoil piles are graded away from the highwall, erosion may be as bad or worse as when graded toward it unless good water management practices are followed such as diversion ditches across the top of the highwall, ditches or terraces across the slope to break the slope length, and control structures to remove the water from the mining area.

Underground Mines

During the period when an underground mine is active, water must be removed either by gravity or by pumpage. The characteristics of this water will vary from seam to seam and even within the same mine. Following active mining, mines below drainage usually fill with water and are often no longer a source of pollution. However, those above drainage continue to discharge polluted water for decades.

The Appalachian Study (1969) reported that active underground mines produced 18.8 percent of the acid mine drainage and inactive underground mines 52.5 percent. An additional 9.2 percent came from a combination surface-underground mining. Thus, underground mines were involved with 80.5 percent of the acid mine drainage.

Siltation is not usually associated with underground mines; however, the waste "gob" removed and piled outside the mine is a major source of silt, acid mine drainage, and often air pollution.

Whereas control technology for surface mines is highly developed, the technology for underground mines is severely limited.

Refuse Piles and Slurry Ponds

Associated with many coal mines is a cleaning or processing plant where the coal is processed to remove dirt and impurities present in the coal. Two types of wastes - refuse and slurry - are discharged from a cleaning plant. The refuse is the coarse portion of the waste consisting largely of coal intermixed with pyrites, sandstones, clays, and shale. Historically, refuse has been piled adjacent to the cleaning plant and has created major silt and acid water pollution and air pollution. Slurry is the fine reject material which contains mostly coal, shale, and clay. The slurry is usually placed in lagoons adjacent to the plant. Slurry can create major sediment problems in streams when it is discharged directly to the stream or escapes from lagoons because of poor design, construction, or maintenance. Upon abandonment, slurry lagoons continue to be a menace unless they are stabilized. Often slurry ponds are not acidic.

CONTROL OF MINE DRAINAGE

Acid Problems

The ultimate solution to the acid mine drainage problem is preventing its formation. As noted in equations 1 through 4, the reaction is dependent on air (oxygen) and water coming in contact with the sulfides. In addition to water being a reactant, it serves as the transport media for removing the pollutants. All prevention techniques are based on excluding water and/or air from the mining environment.

Air: Air is necessary during the active operation of an underground mine. After the minerals have been extracted, excluding air should be an integral part of the mining plan. As areas are worked out, blockages should be made to prevent air from entering that section of the mine. Mines should be developed downdip so that they flood when abandoned. In this manner, water serves as an oxygen barrier. Injecting solid material into the mine, such as stope filling, should be encouraged and expanded. Not only can the mine drainage problem be decreased by blocking the flow of air, but a solid waste disposal problem can be resolved simultaneously.

Sealing adits to prevent air from entering an underground mine has been in practice in the coal fields since the 1920's. This procedure at its best has only been marginally effective. Seals can be built to prevent air from entering the adit, but air reaches the mine readily through the fractured outcropping and overburden. With each change in barometric pressure, air is pumped in and out of the mine. Air sealing should not be considered as an acceptable method.

Bulkhead or hydraulic mine seals have been shown to be successful (Foreman 1972). For this method, a seal is built in the adit and the outcrop is grouted to prevent water from leaving the mine. In time, the mine workings are flooded and oxygen is excluded from the sulfides.

Excluding oxygen from the active surface mine is not feasible. Usually there is a delay between the time the sulfides are exposed to air and acid mine drainage is formed. High sulfide bearing material should be exposed for the shortest time possible. As part of the mining operation, this material should be covered with material containing little or no sulfides. The saving and replacement of top soil should be practiced. The cover material acts as an oxygen barrier. Wind and diffusion are the only driving forces for moving air through the cover material to the sulfides. The cover material should be vegetated with grasses, legumes, shrubs, forbs, etc. Not only does the vegetation serve to stabilize the cover material and prevent it from eroding, but upon dying, the vegetation decays and acts as an oxygen absorber.

Refuse dumps at mines are major sources of mine drainage and should be constructed to prevent air movement into them. Sound techniques are compacting waste material as it is deposited at the dump and sandwiching layers of compacted clay between layers of waste. The slopes of the dumps should be kept to 33 percent or less to prevent wind from driving air into the pile. Upon abandonment, the surface of the pile should be sealed with an air barrier. Although many different materials have been evaluated, soil still remains the best. As in the case of surface mines, the surface should be vegetated.

Water: Enough water is usually available in the moist air within an underground mine or within the material itself in a surface mine or waste dump to meet the requirement for the formation of mine drainage. The other function of water is as a transport media. It flushes the oxidation products from the sulfide and carries them into the environment. By controlling the water, these products can be contained.

Provisions should be made to prevent water from entering the mining environment, except where it is to be used for flooding and as an oxygen barrier. Diversion ditches, dewatering of the mine, and sealing of fractures are just a few of the methods available. Water that does enter the mine should be removed as rapidly as possible.

Silt Problems

The control of silt from surface mines starts in the mine planning stage and follows through mining and final reclamation. During the planning stage, water handling throughout the operation should be carefully planned. This stage includes the location of diversion ditches to keep water out of the mine working, protection of natural drainageways, location of silt traps and basins, and the selection of a mining method to minimize erosion and landslides. The states of Kentucky (1973) and West Virginia (1972) have developed drainage handbooks as guidelines. In recent years several new mining methods such as slope reduction, box cut, and block cut have been developed to reduce silt and slides (Grim 1972). The removal, storage, and replacement of topsoil are other valuable tools in erosion control. Backfilling and planting should follow mining closely to minimize the period that bare material is exposed. Grading should be planned to keep slope length and steepness to a minimum. Terraces and benches should be included to reduce runoff rate. Final grading should be across the slope.

Grasses should be planted on all areas for rapid erosion control, and trees may then be planted if needed or desired. Before planting, soil analysis should be made and the proper fertilizer and lime added. On steeper slopes, mulches may be needed.

In some cases the silt basins may not be capable of reducing the sediment load to an acceptable level because of the colloidal nature of the material. The addition of lime, alum, and other flocculating chemicals might be required in conjunction with the silt basin.

Treatment

Treatment has three places in the acid mine drainage scheme: (1) during active operations to produce a water acceptable for discharge to a stream, (2) in those situations where the production of acid mine drainage cannot be prevented, and (3) in those cases where water is needed for industrial or domestic use.

Neutralization: The most commonly used method for treating acid mine drainage and removing heavy metals is neutralization. A typical system would include adding an alkaline reagent and mixing, aerating, and removing the precipitate. Alkaline reagents that may be used are ammonia, sodium carbonate, sodium hydroxide, limestone, and lime. In most cases, lime is used because of its lower cost and higher reactivity.

Most heavy metals tend to precipitate as the pH is raised. Metals such as copper, zinc, iron, aluminum, manganese, nickel, and cobalt can be reduced to low levels (less than one-half mg metal/l) with pH adjustment, precipitation, and solids separation.

In removing iron, aeration is used to convert the ferrous form to the ferric form to take advantage of the precipitation of ferric iron at a lower pH.

In most cases, lime is used for neutralizing. Except for limestone, lime is the cheapest reagent and reacts rapidly. Lime and limestone unfortunately result in a voluminous sludge. Although limestone is cheaper and produces a denser sludge, it is not effective above a pH of 6.5 because of the slow attack of limestone by acidity at higher pH's. Two-stage treatment with limestone followed by lime appears to offer the advantages of both reagents.

Although neutralization can be used to remove heavy metals and a portion of the sulfate, the resulting water is high in dissolved solids and sulfate. The disposal of the sludge is also a problem.

Ion Exchange: Various ion exchange schemes had been applied to the treatment of coal acid mine drainage (Holmes 1972). These schemes can upgrade the water quality to potable use. Modification can be incorporated to recover heavy metals. Ion exchange has not received wide acceptance because of difficulties encountered with resin fouling, interfering ions, limited loading capacity, cost of operating and disposal of regenerating solutions. Further development is needed.

Reverse Osmosis: Reverse osmosis (R.O.) has effectively removed multivalent ions from mine drainage, producing a near potable water. All heavy metals should be removed at about this same level (99 percent or better). Reverse osmosis is a concentrating process in which the pollutants are contained on one side of a membrane while the water passes through. Water recoveries (percent of water fed to unit that is available as treated water) have been as high as 90 percent. Water recovery is limited by the precipitation of material on the membrane when they have been concentrated beyond the materials saturation point. Calcium sulfate is usually the first material to be precipitated in mine drainage. Equations have been developed to predict the highest water recovery allowable under any influent condition (Wilmoth 1972).

Summary

Disturbing the earth to remove any material, whether by surface or underground methods, will change the environment. Trout habitat will suffer if measures are not taken to control the pollutional aspects of mine drainage. We must strive to develop methods of controlling these discharges, enact strong mining laws, and pursue strong enforcement of the laws.

With our present technology, most acid mine drainage problems can be controlled during active mining and upon abandonment of surface mines and refuse piles. This statement cannot be made of underground mines. In the majority of cases, acid mine drainage cannot be controlled from abandoned or orphaned underground mines.

We have limited technology for controlling silt and landslides from surface mines. Great strides are being made in these areas, and we can be optimistic.

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STREAM CHANNELIZATION; AN ENGINEERING AND BIOLOGICAL REVIEW

Raymond V. Corning^{1/}

ABSTRACT — Peak rate of runoff estimates, estimated by different personnel and formulas, but for the same channels, disclosed variations exceeding 100%. Error or willful bias in the Manning equation for water discharge apparently shifts results logarithmically as the value of n (a judgmental value) increases or decreases. Most for channelization computations can vary widely depending on competency and bias of estimators, data collected or available, choice of formulas, and inherent error.

Objectives of channelization were shown to be to modify the right hand side of the equation $Q = L \cdot W \cdot D \cdot a / T$, in order to influence Q , or stream discharge. Since current velocities, cover, surface area, volumes and depths of streams are vital in determining variation in numbers of trout present in streams (all parameters influenced by the $Q = L \cdot W \cdot D \cdot a / T$ relationship), channelization markedly reduces trout populations. Channel straightening also reduces sport fishing 30 to 300% per mile of stream straightened.

Means for reducing channelization problems include development of a watchdog attitude; impartial reviews of all computations; requiring benefit-cost ratios other than 1+:1; hiring of appraisers to obtain benefit-cost information; developing State agency overseers, and research into which physical parameters affecting stream discharge can be modified with the least effect on stream environment.

ADDITIONAL KEYWORDS: Variability in estimating channel needs. Physical factors of channelization. Relation of physical to biological factors. Possible solutions to problems.

Turmoil in environmental areas is now common because of the shifting in fundamental ways of life and thought. Stream channelization practices are no exception. Historically, our past has been tied to exploitation of natural resources as a necessary and accepted practice. Because the reserves of most natural commodities and resources like unchannelized rivers and streams have declined drastically, rapidly increasing numbers of people recognize that the price tags of exploitation are too high to sanction further resource losses without a careful analysis of other alternatives. Hopefully, all parties will soon recognize that it is not in the National interest to return to old ways, and that the era of true conservation of natural resources has arrived to stay.

This paper, while not an exhaustive treatise on stream channelization, is an attempt to clarify some basic stream channelization procedures and problems, to describe major changes in physical, chemical and biological parameters resulting from channelization and, to suggest ways for conserving, rather than exploiting, our rivers and streams. Perhaps what little clarification of stream channelization issues this paper might provide will in some small way help to reduce the pains of transition.

REASONS FOR EMPLOYING CHANNELIZATION

Stream channelization, sometimes called stream improvement, stream stabilization, or streambank shaping and grading, is carried out by a number of agencies, groups and individuals of varied responsibilities. In all cases channelization has two basic functions; 1) Channel enlargement increases cross sectional area of a channel, thereby increasing the capacity of the channel to convey water, and 2) Channel straightening increases stream gradient while decreasing stream length, allowing water to pass downstream more rapidly.

Reasons given by the Federal Soil Conservation Service for stream channelization include the following; 1) drainage channels to remove surplus water from fields, towns and residential areas, 2) floodwater channels to carry floodwater in quantities sufficient for preventing or reducing the duration of flooding, and 3) diversion channels to intercept runoff, thereby protecting lower lying areas. Stream channelization is also used by this agency for reducing stream sediment transport rates and for reducing groundwater tables.

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The Corps of Army Engineers, Agricultural Stabilization and Conservation Service, Farmers Home Administration, Office of Emergency Preparedness (recently replaced by a new agency), and municipalities, employ channelization for much the same reasons as the Soil Conservation Service. In addition, the U.S. Corps of Army Engineers employs channelization for improving navigation (by eliminating oxbows and deepening and/or widening channels).

State Highway Departments employ channelization to; 1) reduce the size of bridges at stream crossings, 2) reduce the number of bridges needed at stream crossings, 3) increase stream discharge rates, thereby reducing the probability of roadway flooding, 4) lower and/or maintain minimal water table levels near road beds, and 5) relocate stream channels when existing stream sections are wanted for road construction purposes.

From an engineering or hydraulics viewpoint, the objective of stream channelization is to increase the rate of downstream discharge. Q , or the rate of stream discharge in feet per second is often defined as follows:

$$Q = \frac{L \cdot W \cdot D \cdot a}{T}$$

L = length of stream used to determine rate of stream flow for time T .
 W = stream width
 D = average stream depth at W .
 a = resistance of streambed and other obstructions to stream flow (usually a constant)
 T = time it takes water particles in cross section $W \cdot D$ to traverse length L .

$$Q = \frac{L}{T} \cdot W \cdot D \cdot a$$

Obviously, if Q increases as a result of channelization and if the last stated formula defines Q , then one or more variables on the other side of the equation $Q = V \cdot W \cdot D \cdot a$ must also have been affected by stream channelization.

Channel enlargement, (the most common form of stream channelization) increases cross sectional area of a channel, or both W and D and has some effect on a . Channel straightening (another common channelization practice) increases stream gradient by decreasing stream length, thereby increasing the speed at which water passes downstream, or V . Again, a is affected to some extent. The variable a , in addition to being affected as above, can be modified further by removing stream blockages such as downed trees and debris accumulations. Lining the channel with other materials, such as cement can also change a .

PROBLEMS IN DETERMINING NEED FOR CHANNELIZATION

The source of funds for stream channelization activities is an important element when it comes to deciding what techniques will be used to determine whether stream channelization is or is not needed. Most Federal and State funded projects utilize standardized criteria for determining need, except when an emergency is deemed to exist. Standardized criteria are seldom employed when funds are provided by private sources or when Federal or State agencies feel an emergency exists. Municipalities may or may not employ criteria.

PROBLEMS IN COLLECTING AND ANALYZING DATA

A number of computational methods are used for determining anticipated storm runoffs, maximal flood stages, and water discharge capacities of natural and planned stream channels. The methods employed are somewhat dependent on amounts of information on hand or to be collected; for instance whether stream gaging records and rainfall information are available. Generally, this means the less hydrologic information available or collected, the greater the error involved in runoff and flood stage estimates. Certain types of information, no matter how carefully collected or analyzed, are subject to experimental error. This error can be substantial, even if large quantities of information are available.

Competency of the individuals selecting and employing storm runoff, peak flood flow and channel capacity formulas, are of paramount importance. It is up to the individuals in charge to see that available information is used to the fullest, in the most appropriate formulas and to determine what additional information is needed. Should any major factors be overlooked or incorrectly interpreted, additional errors are introduced into final estimates. As a result of the above, channels may be recommended when they are not needed and not recommended when construction would be appropriate.

For further amplification of the above, estimated peak rates of runoff for the same stream sections are provided in Table 1. Rates determined by the rational and U.S.G.S. Dan Anderson methods compare favorably for the information provided. However, both methods are very similar in estimating techniques and the estimates were made by the same personnel. Estimates derived using S.C.S. procedures and other personnel vary widely from the others. Part of the difference is thought to be due to some judgmental error involving the first two estimating methods. Nevertheless, the Table illustrates how markedly flood peak estimates for identical waters can vary when carried out by separate personnel and by separate methods. Obviously, such profound differences could affect decision making and the results of benefit-cost analyses.

Table 1. — ESTIMATED PEAK RATES OF RUNOFF USING THREE SEPARATE ESTIMATING PROCEDURES (Adapted from Annon., 1972, Environmental Evaluation, Pohick Creek Watershed Project, Fairfax, Co. Virginia).

Point	S.C.S. Method Ultimate Flow	Rational Method Ultimate Flow	U.S.G.S. Method Ultimate Flow	Rational % Difference From S.C.S. Estimate	U.S.G.S. % Difference From S.C.S. Estimate	Rational % Difference From U.S.G.S. Estimate
Dam 3	46	46	46	0	0	0
A	453	672	768	+48.3	+ 69.5	-12.5
B	582	1,149	1,208	+97.4	+107.6	- 4.9
C	608	1,065	1,093	+75.2	+ 79.8	- 2.6
D	887	1,567	1,565	+76.6	+ 76.4	+ .1

Water discharge capacities of natural and planned stream channels are often estimated with the aid of an open-channel, slope-area formula. The Manning equation is the most used slope-area formula (Chow, 1964). One constant and four unknowns are incorporated into the formula; $Q = 1.49/n A R^{2/3} S^{1/2}$. Three of the unknowns can be measured precisely in the field. The fourth, n or coefficient of roughness, involves a judgmental decision regarding the degree of retardation of flow as a result of roughness of the sides and bottom of the channel, variation in shape and size of cross sections, types and sizes of obstructions present, amounts and types of vegetation in the channel and channel meandering. Partiality on the part of the estimator, incompetency, inexperience, or lack of sufficient field review data can have a marked effect on final computations (See Table 2). Error tends to vary logarithmically as the value of n increases or decreases.

Table 2. — SOLUTIONS OF THE MANNING EQUATION FOR A TRAPAZOIDAL CHANNEL HAVING ALL FACTORS CONSTANT EXCEPT MANNING'S n (22' bottom width, 1½:1 sideslope, 5.8' design depth, 0.00391 ft/ft hydraulic gradient).

n Value	Channel Capacity in Cubic Feet/Second	Water Velocity of Channel in Feet/Second
0.01	4,073	24.0
0.02	2,037	12.0
0.03	1,358	8.0
0.04	1,018	6.0
0.05	815	4.8

PROBLEMS IN BENEFIT-COST ANALYSIS

Benefit-cost analyses are used to evaluate benefits of a project against costs, with a 1+ to 1 ratio acceptable by Federal Agencies. Normally, costs and benefits are determined in dollar values. Because many intangibles are associated with stream oriented environmental values (such as educational, photographic, etc.), environmental damages have often been neglected. As a result, some costs have been vastly underestimated, while the practice has encouraged a lack of consideration for environmental values and needs.

Land values, flood losses, and flood control gains estimated for use in benefit-cost analyses have been considered restricted information by some agencies and thereby made unavailable to the public or to critical interests. The major reason given has been that land values, etc. were solicited from land owners with the understanding information would not be divulged to others. Obviously, reviews by other agencies or persons wishing to verify the accuracy of projected benefits are blocked by the practice, and the question of proper or improper ratios cannot be decided. Successful isolation of benefit-cost data from outside critiques obviously encourages partiality to creep into projections. It also heightens suspicions of non-privileged groups, even if unfounded.

CHANGES IN PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS

Stream channelization destroys stream habitat for most fish and other stream inhabitants as well as for some wildlife by modifying the existing physical, chemical and biological conditions.

CHANGING OF STREAM WIDTH, DEPTH AND VELOCITY RELATIONSHIPS

Stream channelization profoundly affects stream width, depth and velocity relationships as evidenced previously when the formula $Q = V \cdot W \cdot D \cdot a$ was discussed. Post-channelization stream velocities generally increase during high flows and decrease during low flows when compared to pre-channelization conditions. Average and maximum stream depths follow the same general pattern. Stream width (wetted surface width) after channelization tends to be slightly greater during low flows. Cover along streams is also eliminated during channelization activities as a by-product of width and velocity changes.

Seventy to seventy-seven percent of the variation in numbers of trout (6.9 inches or over) inhabiting a Montana trout stream was attributed to differences in current velocities, stream cover, surface area, stream volumes and stream depths (Lewis, 1969). Current velocity and cover were found to be the two most important factors. Together, the two factors accounted for 66, 66 and 59 percent of the variation in numbers of total trout, brown trout and rainbow trout utilizing the stream. Any changes of stream velocity and cover as a result of channelization, therefore, could be expected to modify the numbers of larger trout maintained by the stream. This relationship must also hold for warmwater fishes, since studies by Tarplee, Louder and Weber (1971) indicated harvestable fish (6 inches or greater) were 75 percent less plentiful in channelized streams of North Carolina.

Maximum estimated stream velocities for artificial channels constructed in Virginia by the S.C.S. have commonly varied from 4 to 7 feet per second. These velocities are in excess of the rates of speed many fishes can attain and are well in excess of those tolerated for sustained periods of time. According to studies carried out by Brett (1965) small sockeye salmon (one of the speediest of river fish) are only capable of maintaining maximum sustained swimming rates of 2.7 feet per second, with adults able to maintain maximum sustained rates of 5 feet per second. From the foregoing, it is obvious fishes can only maintain a continued presence in channels with fast moving water if down logs, rough streambeds and other obstructions adversely affecting the parameter 'n' of the Manning formula are present. Findings of Baldes and Vincent (1969) verify this assumption. They found that as stream velocities increased trout (like other fishes) depended more and more heavily on channel irregularities as resting areas. Hartman (1963) also found that as rates of flow increased brown trout became more dependent on the microhabitats provided by physical obstructions.

CHANGES IN STREAM SINUOSITY

Stream sinuosity (defined as the ratio of the length of the channel in a given curve to the wavelength of the curve) ranged between 1.3:1 to 4:1 for 50 typical meanders selected from different streams in the U.S. (Leopold & Langbein, 1966). Based on these findings, a mile of channelized stream forming a straight line would reduce natural stream length by 0.3 to 3 miles. Percentage wise, sport fishing opportunities (or standing crops of organisms) would be reduced 30 to 300 percent for each mile channelized.

OTHER CHANGES

Maximum, minimum and overall ranges of stream temperatures, pool riffle ratios; dry season and wet season flows, streambed substrate compositions, allochthonous energy cycles; turbidity levels; pH; nitrate and phosphorus levels; food chain relationships and reproductive cycles are other parameters adversely affected by stream channelization. Is it any wonder that a study carried out by Elser (1968) confirmed that standing crops of trout were greatly reduced in channelized stream sectors? Trout were 78 percent more abundant in the unaltered mountain sections than in channelized sectors of the mountain stream.

MEANS FOR REDUCING CHANNELIZATION IMPACTS

A principal overseeing agency in each state, as an arm of State Government, would provide the best assurance that stream channelization activities were reviewed impartially for error and channelization needs. It would also allow proper regulation of activities. The appointed agency should not have parallel responsibilities for furthering or for carrying out stream channelization (no vested interests). Only a State agency would be in a position to properly police Federal, State and private stream channelization activities. Appeal procedures should be developed by this agency along with criteria which would apply to any proposed stream channelization.

Authorities for seeing that designated criteria were followed should be granted to the selected agency. While many States already have adequate regulatory statutes for bringing about necessary compliance, for the most part these authorities are scattered among agencies. Necessary authorities should be consolidated and transferred collectively, or if no authorities exist, statutes should be drafted. In either event, legislative action would probably be required.

An additional advantage of single agency control would be that the accumulation of channelization projects over time and on a watershed basis, could be monitored and evaluated as to possible increases in flood hazard.

RESEARCH NEEDS

Not all elements on the right hand side of the equation $Q = L \cdot W \cdot D \cdot a / T$, or $Q = V \cdot W \cdot D \cdot a$ must be modified in order to accomplish the aim of stream channelization, that is an increased rate of flow for channelized sectors. Properly designed studies are now needed to test the impact that individual elements have on stream biota. The element or elements most adversely affecting stream environments can thus be detected. Also, the elements exhibiting minimal impacts can be studied to determine the latitudes within which they can be modified without undue consequences. Hopefully, results from such studies can be used to develop new stream channelization criteria. These criteria could be used to determine the desirability of channelization and would minimize environmental damages when channelization was deemed essential.

CONCLUSIONS AND RECOMMENDATIONS

A basic review of engineering practices used in determining need for channelization leads one to conclude no estimates are absolute, with marked variations in results and conclusions possible. Due to the chance for errors, a 1+:1 ratio of benefits to costs appears highly inappropriate for justifying stream channelization. A minimal ratio of 2:1 (benefits:costs) appears more acceptable. The need for complete computational reviews by sources other than vested interests on whether sufficient hydrologic data was available or collected, is also obvious. Competency of personnel, bias of estimators, available information, choice of formulas and inherent error of formulas bear heavily on final calculations. Benefit-cost procedures need to be modified in a way which takes into account intangibles. Also, to avoid any problems involving restricted information in benefit-cost analyses, independent land appraisers (rather than landowners) should be hired to provide data. Additionally, a principal overseeing agency in each State should be selected and authorized to develop emergency and non-emergency channelization criteria, to carry out reviews and to enforce adopted regulations. The need for computational reviews, as well as checks on whether sufficient hydraulic data was available or collected by sources other than vested interests, is also obvious.

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PRODUCTIVITY OF SOUTHEASTERN STREAM ECOSYSTEMS

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Abstract.--Streams differ from terrestrial ecosystems in a number of characteristics. Most studies indicate the main source of energy to streams is in allochthonous inputs. A generalized Southeastern United States trout stream model is proposed and examples of organisms performing various functions are described.

Additional keywords: Model

Ecologists have used the words "productivity" and "production" in a variety of ways. In his classic paper on trophic dynamics, Lindeman (1942) used productivity as the rate of contribution of energy from one trophic level to the next. Ivlev (1945) made a clear distinction between production and productivity. He used production as the formation of new biomass by a group of organisms in a given time and productivity as the capacity of a body of water to produce a specified "product of interest". This distinction has been preserved by most aquatic biologists (Warren 1971); however the terms are used interchangeably by ecologists (Odum 1971, p. 43; Phillipson 1966, p. 6; Collier et al. 1973, p. 375).

Production may be defined at several levels of biological organization. At the individual level, production is essentially the growth rate of the organism. Material that is ingested (I) can be partitioned into egestion (E) and assimilation. Assimilation can be further partitioned into respiration (R) and production (P), so the $P = I - E - R$.

Production at the population level is usually estimated from growth rates, using the formula $P = GB$, where P is production, G is growth rate and B is biomass. The problem is complicated because different age classes have different growth rates. Methods of performing these calculations have been developed by a number of authors, e.g. Ricker (1946) and Allen (1951). The various methods have been applied to a population of mayflies by Waters and Crawford (1973).

Two points should be brought out. First, production in this sense is Lindeman's productivity minus respiration. Second, as used by biologists working at this level of organization, production is total tissue elaboration by the population whether or not it survives to the end of the period.

A similar concept of production can be extended to trophic levels. Production by plant trophic levels is termed primary production. Total fixed

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carbon is gross primary production and net primary production is gross primary production minus plant respiration. Methods of measuring production at higher levels are not well defined, primarily because of lack of a good definition of trophic level. A method developed by Hynes and Coleman (1968) has some usefulness, but is clearly an approximate method.

Production at a community or ecosystem level usually refers to net production. Net community production is the rate of storage of organic matter not used by consumers. Clearly an ecosystem which is at a steady state has zero net production.

In the time and space allotted to us it would be impossible to consider all factors affecting stream productivity (or production). A number of factors are important in controlling benthic invertebrate populations. Some of these are: current speed, temperature, substratum, oxygen, water acidity, alkalinity, shade, and floods. Hynes (1970) gives an excellent review of existing literature on these topics, their interrelations and effects on stream bottom fauna. This manuscript has been oriented toward trophic aspects of stream productivity, and problems of a theoretical approach to stream ecology.

THE ECOSYSTEM APPROACH TO STREAM ECOLOGY

In the past several decades there has been a shift by many ecologists from an individual and population oriented approach to a community and ecosystem oriented approach. This trend has only recently become apparent in stream ecology.

Shelford and Eddy (1929) noted that plant ecologists usually assumed that there were no permanent fresh water communities. Armitage (1958) found that species occurred along a continuously fluctuating environment and that discrete communities could not be described. Shelford and Eddy's hypothesis that permanent stream communities do exist has been upheld by a number of other studies (Sedell 1972). The study by Gersbacher (1937) "suggested the existence of but a single major community and its developmental stages" in the Sangamon River. Many previous and subsequent studies (reviewed by Hynes 1970) have shown distinct faunal zonations in streams associated with physical changes of the stream environment. Precise definitions of stream zones are probably not possible (Hynes 1970), but the notion of stream communities and stream ecosystems should be as useful and stimulating to stream ecology as it has been in other areas of ecology. With few exceptions, stream ecology has been dominated by zoologists (Cummins 1972) and only recently have any stream studies considered streams as interacting wholes (e.g. Sedell 1972; Boling, Peterson and Cummins 1974; Krumholz and Neff 1970).

Stream ecosystems are different from other ecosystems in several ways. Odum (1971) lists six ecosystem characteristics: 1. energy circuits, 2. nutrient cycling, 3. foodchains, 4. diversity, 5. development and evolution and 6. control. In the first three of these characteristics stream ecosystems have distinct differences from the commonly held view of ecosystems. The energy circuits of stream ecosystems are often not dependent on photosynthetic fixation

of energy but instead are supported by allochthonous energy inputs. Nutrient cycles are essentially non-existent in streams. Instead there is a direct flowthrough of materials. The food chain concept of Lotka (1925) and Lindeman (1942) has not been very useful in theoretical approaches to stream ecology. Instead a conceptual framework specifically related to the stream biota has proven more useful.

THE ENERGY CIRCUIT OF STREAM ECOSYSTEMS

Primary production may be very important in lotic ecosystems. In Table 1 we have accumulated a number of estimates of primary production in flowing waters. These values may be compared with estimates of gross primary production in terrestrial and marine ecosystems. The minimum gross primary production Odum (1971) lists is $40 \text{ g/m}^2/\text{yr.}$ ($5000 \text{ cal.} = 1 \text{ g}$) for deserts and tundras. The maximum is $4000 \text{ g/m}^2/\text{yr.}$ for estuaries, reefs and wet tropical and sub-tropical forests. In small headwater streams such as Bear Brook and Walker Branch primary production is extremely small. In larger streams however the estimates of production are in the range of the highest that have been examined.

In Table 2 we have compared estimates of gross primary production with allochthonous leaf fall inputs. In most cases allochthonous inputs exceed autochthonous fixation. It should be pointed out that in this table we have considered only leaf fall. In large streams particulate detritus and dissolved organic matter carried by the stream water may be significant energy inputs. In the Thames River, for example, community respiration in places exceeded primary production (Mann et al. 1972). This is a common occurrence in polluted streams. Even in headwater streams the dissolved organic matter input from ground water may be significant. At Bear Brook, Fisher and Likens (1973) measured this source of energy as $300 \text{ g/m}^2/\text{yr.}$ Considering all allochthonous inputs, leaf fall, sub-surface flow and stream flow, the ratio of allochthonous to autochthonous inputs at Bear Brook was 628.

The importance of detritus to marine organisms has been studied for a number of years (Darnell 1967), however, the importance of allochthonous detritus to stream ecology has only recently been recognized. Egglisshaw (1964) noted that in Macan's reviews of stream ecology (Macan 1961, 1962) there was no mention of any statistics which considered plant detritus as an ecological factor. Scott (1958) considered the importance of dead leaves from the adjacent land to the biological balance of streams. Nelson and Scott (1962) first quantified the role of allochthonous detritus in streams. The importance of imported organic matter was emphasized by Hynes (1963). Ross (1963) found that the distribution of Trichoptera species in small streams was significantly influenced by the surrounding vegetation. In Doe Run, Minckley (1963) found a major dependence of primary consumers on detrital material. Darnell (1964) reported that the overwhelming mass of plant detritus consumed by benthic organisms in a Mexican stream was of terrestrial origin. The paper by Egglisshaw (1964) in which he showed a significant correlation between the bottom fauna and plant detritus was probably most influential in reorienting stream ecology. Since that time considerable stream research has concerned detrital energy sources (Table 2).

Table 1.--Gross Primary Production Estimates in Flowing Waters

<u>Stream</u>	<u>Reference</u>	<u>GPP (g/m²/yr)</u>
Truckee River, Nevada	Thomas and O'Connell 1966	1715-6022 <u>d/</u>
Root Spring, Massachusetts	Teal 1957	142 <u>c/</u>
Bear Brook, New Hampshire	Fisher and Likens 1972, 1973	2 <u>a/</u>
Madison River, Wyoming	Wright and Mills 1967	1314 <u>d,e/</u>
White River, Indiana	Denham 1938 <u>f/</u>	88-20805 <u>d/</u>
Florida springs	Odum 1956	219-21535 <u>d/</u>
Itchen River, England	Butcher, Pentelow and Woodley, 1930 <u>f/</u>	146-5110 <u>d/</u>
Lark River, England	Butcher, Pentelow and Woodley, 1930 <u>f/</u>	193-14235 <u>d/</u>
Thames River, England	Mann et al. 1972	807 <u>a/</u>
Oconee River, Georgia	Nelson and Scott 1962	1562 <u>a,c/</u>
Red Cedar River, Michigan	Ball, Kervern and Linton 1969, Grzenda, Ball and Kervern 1968 <u>g/</u>	4-831 <u>d/</u>
Hope Creek, North Carolina	Hall 1972	155 <u>b,e/</u>
Drift Creek, Oregon	Lane and Hall 1971	97-486 <u>b,d,e/</u>
Cone Spring, Iowa	Tilly 1968	384 <u>a,c/</u>
Artificial stream	Kervern and Ball 1965	487 <u>a,d/</u>
Artificial stream	McIntire et al. 1964	465-914 <u>b,d,e/</u>
Ohanapecosh Hot Springs, Washington	Stockner 1968	612 <u>e/</u>
Drakesbad Hot Springs, California	Lenn 1966 <u>h/</u>	5110-8759 <u>d,e/</u>
Silver Springs, Florida	Odum 1957	4102 <u>a/</u>
Streams, North Carolina	Hoskin 1959 <u>i/</u>	3577 <u>d/</u>
Ivel River, England	Edwards and Owens 1962	1862 <u>b,e/</u>
Walker Branch, Tennessee	Elwood and Nelson 1972	10-16 <u>c,d/</u>
Columbia River, Washington	Cushing 1967	33-460 <u>c,d/</u>

a/ 5000 cal. = 1 g.

b/ 1 gO₂/m²/yr. = 3.76 gC/m²/yr. (Stockner 1968).

c/ Gross production = 1.8 net production.

d/ 1 g/m²/yr. = 365 g/m²/yr., probably results in an overestimate since most measurements are made during the summer.

e/ 1 gC/m²/yr. = 2 g biomass/m²/yr. (Odum 1971).

f/ From Odum (1956).

g/ Data from Grzenda (1960) and King (1964).

h/ Reported by Stockner (1968).

i/ Reported by Thomas and O'Connell (1966).

Table 2.--Comparison of Gross Primary Productivity with Allochthonous Leaf Fall Inputs

<u>Stream</u>	<u>Reference</u>	<u>Leaf fall input g/m²/yr</u>	<u>Leaf fall input/ Gross primary productivity</u>
Thames River, England	Mathews and Kowalczewski 1969; Mann et al. 1972	23.2	.03
Stream, Pennsylvania	Vannote 1969	200-800	2 <u>a/</u>
Shallow, fast-flowing streams	Egglishaw 1968		4 <u>a/</u>
Streams, Oregon	Chapman 1966; Chapman and Demory 1963	coho salmon production	9.7
Root Spring, Massachusetts	Teal 1957	470 ^{b/}	3.3
Morgan's Creek, Kentucky	Minshall 1967	input to Gammarus minus	9 <u>a/</u>
Bear Brook, New Hampshire	Fisher and Likens 1972, 1973	528 ^{b,d/}	264 <u>d/</u>
Oconee River, Georgia	Nelson and Scott 1962	input to consumers	2
Hope Creek, North Carolina	Hall 1972	476	10.6 <u>c/</u>
Bere Stream, England	Westlake et al. 1972		7.3
Cone Spring, Iowa	Tilly 1968	125 ^{b/}	.3
General stream model	Cummins 1971	800	2
Coweeta, WS 6, old field	Webster, unpublished	267	
Coweeta, WS 17, white pine plantation	Webster, unpublished	289	
Coweeta, WS 18, hardwood forest	Webster, unpublished	352	

a/ A qualitative estimate.

b/ 5000 cal. = 1 g.

c/ For Hope Creek, the first figure was obtained from Hall's stream input data, the second figure is Hall's estimate for utilized energy.

d/ Includes litter blow-in.

NUTRIENT CYCLING IN STREAM ECOSYSTEMS

Terrestrial and lake ecosystems are characterized by nutrient cycles. Regeneration of nutrients by decomposition is essential for energy flow in these ecosystems. Because of the dominance of allochthonous inputs, streams are not dependent on nutrient regeneration. Also the flow of water essentially prevents any nutrient cycling (Scott 1958).

The physical effects of the unidirectional flow of water were discussed by Krumholtz and Neff (1970) who emphasized that this flow is the key to understanding stream ecosystems. Thienemann (1953, as cited by Margalef 1960) compared the microcosmic character of lakes and the "flow of a river, a spatial manifestation of a continuous state of change" (quote from Margalef 1960).

The movement of biotic and abiotic materials downstream is well documented (e.g., Leopold 1949, Waters 1972). Margalef (1960) pointed out that in a watercourse with only laminar flow no population could maintain itself, but turbulent flow is just one of the reasons why "...all organisms do not end up in the estuary" (Patrick 1970). The "colonization cycle" of Müller (1954, as reviewed by Waters 1972, and Elliott 1971) in which emergent females migrate upstream to oviposit has been hypothesized as the method by which the fauna of upper reaches of streams are replenished. A number of examples of upstream movements by emergents have been reported in support of this hypothesis (e.g., Roos 1957, Elliott 1969). Additionally, a number of other papers (Minckley 1964, Momot 1966, Brusven 1970, Elliott 1971, and others listed by Elliott 1971) noted the upstream movement of benthic organisms. More than nutrient cycling, however, these upstream movements represent a cycling of genetic information essential for the maintenance of stream populations.

Juday et al. (1932) suggested that the upstream migrations of salmon may be important in resupplying essential nutrients to upstream areas. Donaldson (1967^{2/}) and Krokhn (1967^{2/}) have demonstrated the role of migrating adult salmon in phosphorus budgets of lakes and Fittkau (1970) has hypothesized a similar situation in Amazon effluents. Following a release of radiophosphorus, Ball, Wojtalik, and Hooper (1963) found a significant number of tagged insects upstream from the release site. However, Hall (1972) showed that the upstream movement of phosphorus by migrating fish was an extremely small percentage (<.1%) of total downstream movement of phosphorus.

MODELING STREAM ECOSYSTEMS

The modeling of ecosystems in trophic levels has been extremely valuable to theoretical studies in ecology. However, the typical trophic model consisting of producers, herbivores, carnivores, and decomposers has distinct limitations to stream ecology because, as discussed above, photosynthetic production is often not the primary source of energy. Odum (1956) used a simple trophic model, but his interest was in systems with high levels of primary production (Table 1). Other models have taken one of essentially three different approaches, physical, taxonomic or functional.

^{2/}

As reviewed by Hall (1972).

The model structure used by Fisher and Likens (1973) which emphasized inputs and outputs to the stream ecosystem, can be categorized as a physical model. The wide variety of hydrologic and hydrologic transport models currently in use can also be placed in this category.

Minshall (1957) used a taxonomic approach. In his synthesis he placed each species in a specific trophic level based on its most common food habit. He used the trophic level concept to apply to both algae and detritus consumption. This taxonomic approach was generally followed by Hynes (1970) and Mann et al. (1972) though taxonomic groups were not placed in trophic levels but in functional categories such as filter feeders, browsers, grazers, and predators.

Coffman, Cummins, and Wuycheck (1971) and others have noted that most insects eat a variety of foods making it difficult to define a species as herbivore, detritivore, or carnivore. Even organisms which have a fairly specific diet at one stage of the life cycle may alter their feeding habits at another stage of the life cycle. Based on this experience Cummins (1971) presented a stream model which emphasized the functional aspects of detritus utilization. Expansion of this model necessitated the introduction of the "paraspecies" concept (Boling et al. 1974a). A paraspecies grouping may combine various immature stages of different insect species, all with common feeding habits. The dynamics of microbial and mechanical detritus breakdown were expanded in another submodel (Boling et al. 1974b).

At Coweeta where we are studying three very small first order streams we used both a functional approach and a taxonomic approach. We placed insects into three categories, shredders, collectors, and predators but placed crayfish and salamanders in separate categories because of their abundance and importance in these streams.

Any stream model must be specific to the actual stream being studied. However in most cases a functional approach emphasizing the role of organisms in detritus breakdown will be preferable to a trophic or strictly taxonomic approach.

GENERAL SOUTHEASTERN TROUT STREAM MODEL

As a model structure which seems appropriate to streams that can be categorized as Southeastern trout streams we propose the model structure shown in Fig. 1.

There are numerous examples of organisms in streams performing the functions in Fig. 1. With the exception of crayfish and vertebrate predators most of these are aquatic insects. As previously mentioned for most of our trout streams in the Southern Appalachians the main source of energy is allochthonous, primarily leaf litter from terrestrial communities. This leaf material, large particulate organic matter, LPOM in Fig. 1, is colonized by fungi and bacteria (Triska 1970). Studies have indicated there may actually be an increase in nitrogen content of leaves after wetting, apparently due to assimilation by the fungi and bacteria populations on the leaf surface (Kaushik and Hynes 1968).

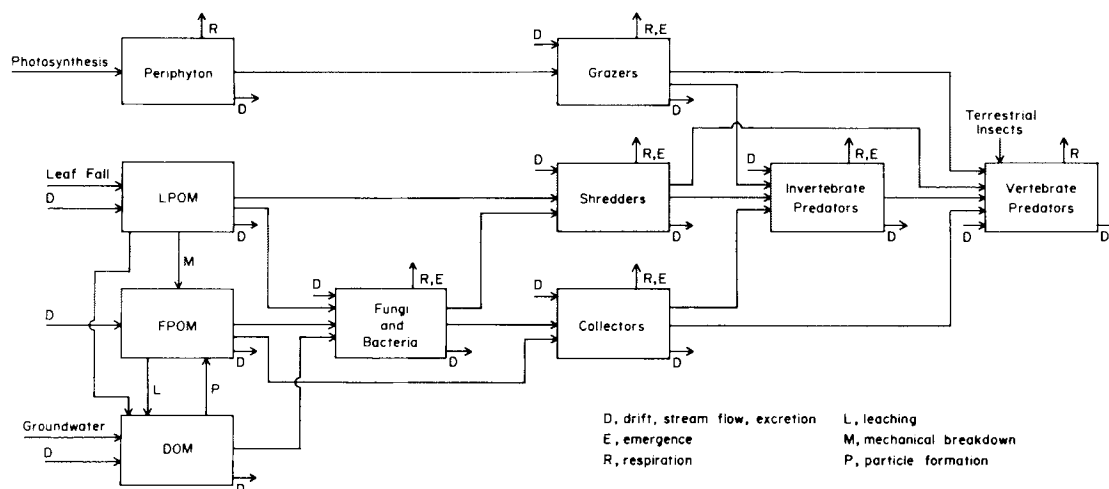


Figure 1.--Generalized Southeastern Trout Stream Ecosystem Model.

The large leaf material and associated microflora are fed on by large particle detritivores or shredders (Cummins 1973). In the southern Appalachians some of the common examples of shredders are Peltoperla maria Needham and Smith (Plecoptera) (Wallace et al. 1970), Pteronarcys scotti Ricker (Plecoptera) (McDuffett 1970), Tipula (Diptera) (Vannote 1969), Pycnopsyche spp. (Trichoptera) (Mackay 1972) and crayfish. The feeding of these shredders results in a large number of smaller detritus particles (from mechanical breakage and feces) or fine particulate organic matter, FPOM in Fig. 1. During the initial period that leaves are in water they may lose a considerable portion of their weight by leaching. Recently (Lush and Hynes 1973) it has been shown that this leachate, dissolved organic matter or DOM in Fig. 1, can form aggregates (FPOM in Fig. 1). These particles are formed both abiotically and biotically and such particles represent another possible food source for fine particle feeders (Lush and Hynes 1973).

The aquatic insects have numerous adaptations for collecting fine particulate organic matter. Isonychia spp. (Ephemeroptera) possess a fringe of fine hair on their forelegs with which they filter organic matter from the water as they face directly into the current. A number of insects spin webs at the apex of silk tubes and use these webs to capture drifting organic particles, e.g. Calopsectra spp. (Diptera). Perhaps some of the most sophisticated

structures for collecting food materials in streams are found in the net spinning Trichoptera or caddisflies. Various species spin nets with individual mesh openings ranging from less than $100 \mu^2$ to over $200,000 \mu^2$. By micro-distributional patterns with respect to current velocity, individual species are able to utilize a wide variety of drifting particle sizes at any one locality. Thus, within a taxonomic group there may be considerable partitioning of food resources in regards to both type and size of food (Wallace unpubl. data).

Although most studies have indicated allochthonous detritus as the major energy input to streams (Table 2) there are a number of insects that feed primarily on periphyton. Blepharicerids (Diptera) and *Neophylax* spp. (Trichoptera) are two examples of "grazers" that feed primarily upon periphyton.

Examples of predaceous aquatic insects that are fairly abundant in the southern Appalachian streams are immatures of Odonata, Perlidae (Plecoptera) and Corydalidae (Megaloptera).

Tebo and Hassler (1963) studied the food of trout in Western North Carolina and concluded that trout are opportunistic feeders. All examples of shredders, collectors, grazers and predators cited above (and numerous others fitting the above categories but not specifically listed) were found in trout stomachs in Tebo and Hassler's study.

The data in Table 2 and Fig. 1 show that successful trout management practices from the standpoint of available food is related to terrestrial management practices. Undoubtedly, actions that reduce or impede the inputs of terrestrial litter into our streams (Table 2, compare Coweeta data) are going to result in decreased production of trout food organisms. We presently need much more information on various aspects of these land-water interactions.

SUMMARY

Until recently much of the work on streams has been largely descriptive in nature. Future work must proceed toward an ecosystem approach and large scale modeling of streams. However, such an approach cannot ignore the internal dynamics of the ecosystem. We need considerably more information about the individual processes that occur in the stream. One of the more pressing needs is adequate information on the precise roles of fungi and bacteria as they influence large and fine particle detritivore feeding. Also adequate information on seasonal cycles of individual species, including feeding habits and partitioning of food resources as influenced by age, species, temporal and spatial microdistribution patterns is essential. For example, some of the problems associated with the conceptualization in Fig. 1 have been mentioned with respect to the net spinning Trichoptera since within this one group considerable food partitioning is occurring. Finally, there are two basic areas that consistently impede stream studies. These are adequate, reliable sampling techniques and the problem of identification of stream organisms, especially the immature insects.

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STREAM CLASSIFICATION SYSTEM FOR WEST VIRGINIA

by

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ABSTRACT

A classification system based on four factors--esthetics, access, use, and productivity--was developed for West Virginia streams. Each factor was weighted according to its importance to coldwater fish production and was rated numerically from 1 through 5 with a 5 rating given to the most desirable condition. Productivity ratings were determined by computation of a numerical score based on optimal water quality characteristics for coldwater fish production. Each characteristic was assigned a weighting factor based upon its judged importance. Classification was determined by the summation of the products of each factor and its respective multiplier. Classification categories ranged from pristine streams of multistate importance (class 5) to highly polluted streams of only local importance (class 1). Data from Rich Creek, West Virginia was used to demonstrate the use of the classification system.

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INTRODUCTION

The protection of existing stream ecosystems from pollution, overuse, and channelization is necessary if the increasing demands for fishing are to be met. Stream management is one mechanism to insure protection. However, some streams are more valuable and/or more fragile than others. Protection of these streams is especially critical. The first step toward intelligent stream management is to describe these streams. Identification of a stream's value to man requires that we obtain baseline data on fish populations, water quality, and angler utilization. Several states have recognized the importance of rating the value of their streams and have integrated baseline information and professional judgment into stream classification systems.

Montana's stream classification system is based on a numerical rating utilizing an evaluation of esthetics, productivity, availability to the angler (access), and angler use. These factors are weighted according to their judged relative importance, and a total numerical score is determined. Classification is based on this numerical score. Idaho currently uses the same format as Montana except that an alphabetical rating is used instead of a numerical rating.

Classification systems in New Jersey and North Carolina are based on the fauna in the stream. The New Jersey classification system is based on standing fish populations as determined by a stream survey. Streams are classified as: 1) trout production waters -- waters suitable for spawning and/or nursery purposes, 2) trout maintenance waters -- waters that support trout throughout the year, and 3) non-trout waters -- waters that will not support trout because of physical, chemical, or biological characteristics of the stream. A fourth category is currently being developed that would identify and classify those streams containing yellow perch (Perca flavescens) and smallmouth bass (Micropterus dolomieu) (Robert Soldwedel, personal communication).

North Carolina classifies streams according to fish fauna present and physical and chemical factors such as stream width, pool depth and type, bottom type, flow, maximum summer temperature, turbidity, alkalinity, and pH (Richardson, 1964). North Carolina further classifies trout waters into trophy trout, native trout, or general trout waters (Hayden Ratledge, personal communication). Special seasons and gear restrictions are applied to each class of trout water.

Montana's stream classification system is perhaps the most complex classification system we have reviewed. This system is based on four major factors. These factors include: esthetics, availability or access, productivity, and angler use or fishing pressure. Esthetics are rated on a scale of 1 (only fair esthetics or a polluted stream) to 5 (a clean and clear stream with wilderness characteristics and high natural beauty). The availability or access rating is also rated from 1 (access nearly impossible) to 5 (access good but not excessively good). The productivity ratings are based on the relative abundance of trout populations. The highest rating is given to streams with fish populations that will support heavy fishing pressure, as determined by fishery biologists. Use or angling pressure ratings are based on creel census

data, U.S. Forest Service campsite use counts, and the subjective opinions of state fishery biologists (Gary Wood, personal communication).

Many states recognize the desirability of a stream classification system and have developed such systems. Many additional states recognize the need to develop such a system as a means of helping protect their diminishing stream resources. New Jersey is currently developing water quality criteria (i.e., criteria for limiting the amount of thermal effluent that can be discharged into any particular class of stream) based on their stream classification system. Virginia, having recognized the value of various stream classification systems, is currently developing a trout stream classification system based on a combination of the systems from North Carolina and Montana (Robert Wollitz, personal communication). West Virginia has also expressed interest in a coldwater stream classification system.

We have proposed a system for describing West Virginia's stream situation to meet the need for a coldwater stream classification system in West Virginia. This system has the same basic framework as the Montana system. However, each factor has been redefined or rewritten to more accurately reflect West Virginia stream conditions. Fishing pressure ratings and values are from Zurbuch's (1962) creel census of five major trout streams. These figures were updated or confirmed by West Virginia Department of Natural Resources personnel (Harvey Beall, personal communication). We developed several subset rating systems within the productivity rating in an attempt to quantify the potential productivity of a stream. The subsets are biological, physical, and chemical parameters considered critical by the West Virginia Department of Natural Resources (Don Phares, personal communication).

The purpose of this classification system is threefold. First, to provide a framework for measuring each stream's relative value to the fishery resources of the state; evaluation of worth is essential if streams that satisfy recreational needs are to be protected from destruction. Second, to give fishery biologists a format outlining the types of data needed for stream management; identification of data gaps can help biologists by emphasizing data necessary for stream classification. Third, to provide a standardized stream survey format requiring field data that are easy to collect and are useful for the evaluation of the potential fishery.

OUTLINE OF CLASSIFICATION SYSTEM

The classification system developed for West Virginia provides the methodology for rating the relative value of each stream. Evaluation is accomplished when the stream is placed into one of five classes on the basis of its esthetic value, access, use, and potential productivity. These classes provide a rough measure of the relative value of each stream.

The five class rating system was selected because it is simple to use and easy to understand, and involves no large or complicated measurements or numbers. In addition, the five class rating system has been successfully used in Montana since 1959 and more recently in Wyoming (Wyoming Game and Fish Commission, 1971).

Although all the factors evaluated in the classification system are important to the potential fishery, some factors are more important than others. We assigned a multiplier of 1 to 4 to each factor to quantify its relative importance. The multipliers, which allow the judged proportional effect of each factor to be applied to stream classification, were selected on the basis of professional judgment of biologists, and were assigned as follows: esthetics, 1; access, 2; use, 3; and productivity, 4.

The final classification of a stream results in its placement into one of the five following classes, based on a derived composite numerical value.

- Class 5 -- cold water fishery of multistate importance
- Class 4 -- cold water fishery of statewide importance
- Class 3 -- cold water fishery of regional importance
- Class 2 -- cold water fishery of local importance
- Class 1 -- stream unsuited for cold water species

The first factor we considered in classifying a stream was esthetic beauty. Ratings are based on natural beauty of the surroundings plus the degree of human development. Although esthetics are important other factors are considered more important. Therefore, the esthetic rating was assigned a multiplier of one with the following descriptions of each rating:

Esthetics x 1

Rating	Description
5	Outstanding natural beauty, unique, and possessing wilderness characteristics; pollution free.
4	Comparable with a stream of rating five but lacking wilderness characteristics; some human development present, such as roads or farms.

Rating	Description
3	Some natural beauty but more common than rating 4 or 5; usually clear with little pollution; flows through attractive agricultural areas.
2	Unimpressive and not uncommon esthetic qualities; human development present but land is not abused; scenery is appealing.
1	Esthetic qualities poor; water quality problems include continuous high turbidity and pollution; lack of stream bank cover. Includes all newly channelized streams.

The second factor considered in classification was availability of fishermen access. Ratings are based on quantity and quality. Excessive access, such as a road bordering a stream, promotes stream bank degradation and hatchery truck following by fishermen. Limited access can curtail fishing pressure on the fishery. The access rating was assigned a multiplier of two with the following ratings:

Access x 2

Rating	Description
5	Satisfactory for modern cars; not excessive; (i.e., no road bordering the stream). Access in terms of posting and availability very good.
4	May be excessive (road bordering the stream). Posting not extensive. Stream bank not restrictive to fishermen access
3	Restricted to roads or trails suitable for 4 wheel drive vehicles, horseback, or foot traffic. Posting not restrictive.
2	Limited by posting, or otherwise restricted.
1	Inadequate because natural or man made restrictions nearly exclude fishermen.

The third factor considered in the classification system was the amount of use or fishing pressure a fishery receives. Very heavy fishing pressure is undesirable because stocked fish are quickly removed from the stream and natural trout populations are generally unable to support such fishing pressure. Very light fishing pressure is also undesirable because underexploitation or underutilization of existing trout populations is likely. Therefore, no one or two ratings are given. According to West Virginia fishery biologists, moderate fishing pressure is the most desirable (Harvey Beall, personal communication). A stream with moderate

fishing pressure receives the highest rating (5). The fishing pressure ratings are based on stocked streams because a large number (196) of West Virginia's trout streams are stocked. The ratings are based on the following figures and were assigned a multiplier of three.

Use x 3

Rating		Description
3	Very heavy	500 angler hours/acre/year
4	Heavy	300-500 angler hours/acre/year
5	Moderate	150-299 angler hours/acre/year
4	Light	50-149 angler hours/acre/year
3	Very light	50 angler hours/acre/year

The fourth and most important factor considered in this classification system, and by far the most difficult and complex factor to access, is stream productivity. Productivity was therefore assigned a multiplier of four. Nine characteristics have been integrated into the productivity rating system. Each characteristic has been assigned a weighting factor, ranging from 1 to 3, based on each characteristic's judged relative importance. Four characteristics have weighting factors of three (pH, water temperature, total alkalinity, invertebrate abundance), one characteristics has a weighting factor of two (turbidity), and four characteristics have weighting factors of one (total hardness, conductivity, phosphates, nitrates).

The range of values expected in West Virginia for each parameter was selected after consultation with state fishery biologists and evaluation of state water quality records (West Virginia Department of Natural Resources, 1969). The range of possible values was divided into 5 subranges that were rated from 1 through 5. The highest rating (5) was assigned to the subrange considered to give optimal coldwater fish production.

We determined the score for each characteristic by multiplying the appropriate subrange rating by its respective weighting factor. The summation of scores for the nine parameters yields a productivity subtotal, which, in turn, is used to determine the productivity class. The productivity class is based on a range of subtotals determined by an acceptable range of ratings for each characteristic. A maximum and minimum productivity subtotal is calculated for each productivity class with the following ranges:

Productivity Class	Productivity Subtotal
5	90-80
4	80-57
3	61-46
2	44-35
1	22-18

The possibility of overlap in the ranges of productivity subtotals exists between productivity classes 5 and 4 and 3. If overlap occurs, the biologist must subjectively decide which productivity class is appropriate for that particular stream.

To determine the classification for a particular stream, the biologist multiplies each factor's rating by the appropriate multiplier. The summation of the products for each factor determines the overall classification.

The stream class determination is based on a possible total score derived from optimum ratings. Total scores for different stream classes are: 5, 50-45; 4, 44-36; 3, 35-26; 2, 25-20; 1, less than 20. The range of acceptable ratings for each factor was determined after consultation with state and federal fishery biologists in West Virginia.

Data from Rich Creek, West Virginia are used to demonstrate the operation of this stream classification system. Rich Creek has some natural beauty, has little pollution, and flows through an attractive agricultural area. Therefore, the total score for esthetics is 3 (rating) x 1 (multiplier) = 3. The access factor total score is 4 x 2 = 8 (a state-secondary road borders Rich Creek). As determined from a creel census, Rich Creek is subject to heavy fishing pressure. The resulting rating of 4 x 3 yields a use total score of 12. The productivity rating is determined on the basis of the values shown in Table 1. A productivity subtotal of 72 gives a productivity rating of 4. Multiplying the rating by its multiplier (4) yields a total productivity score of 16. The summation of the values for esthetics, access, use and productivity yields an overall score of 39 (Table 2). This score results in Rich Creek being placed in the class 4 stream category.

Conclusion

Stream classification has considerable potential for use in stream management, because classification forces a resource agency to evaluate streams. Evaluation allows identification of data gaps and identification of resources in critically short supply. Classification also forces an agency to consolidate existing data, thereby facilitating maximum use of that data.

Stream classification may not be widely used for many years. Streams will, however, continue to lose the ability to support desirable fish populations as the result of pollution, channelization and other activities. These decreases in the number of fish-producing streams with an increase or stabilization in fishing demand will necessitate decisions. Fishery biologists must decide which streams must be protected to minimize the impact of stream loss on the fisheries resource. This classification system will assist in decision making. To meet future demand, managers must intensely manage the streams protected from destruction if the full potential productivity of such streams is to be realized. This classification system indicates a stream's potential value. The more intense the management, the more apparent the value of this classification system will become. The energy crises of the 1970's and the presence of huge coal reserves in West Virginia make its streams highly susceptible to destruction. The assignment of classifications in accordance with the systems described here could be a valuable step in protecting West Virginia's aquatic resource.

Table 1. Data values used to determine a productivity subtotal for Rich Creek.

Parameter	Actual Data Value	Rating	Weighting Factor	Score
pH	7.0	4	3	12
Water Temperature	78F°	2	3	6
Alkalinity	140 ppm	5	3	15
Invertebrate Abundance	6.0 cc/ft ²	5	3	15
Turbidity	0 JTU	5	2	10
Nitrates	0.6 ppm	3	1	3
Phosphates	6.0 ppm	1	1	1
Total Hardness	160 ppm	5	1	5
Conductivity	220 micromhos	5	1	5
Productivity Subtotal				72

Table 2. Classification of Rich Creek, West Virginia.

Factor	Rating	Multiplier	Score
Esthetics	3	1	3
Access	4	2	8
Use	4	3	12
Productivity	4	4	<u>16</u>
Overall Score			39

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STABILIZATION OF EROSION ON A
MOUNTAINOUS ROAD CONSTRUCTION PROJECT

Robert James Brown and Joseph Mickey, Jr.^{1/}

Abstract.--The successful control of erosion from a mountainous road construction project in Western North Carolina resulted in the preservation of trout habitat. Cooperation between a citizen conservation organization, state and federal agencies and private enterprise was instrumental in the project's success. Methods of erosion control in mountainous terrain are stated and evaluated.

Additional keywords: Highway construction, erosion control, trout habitat, trout, siltation, and sedimentation.

The detrimental effects of siltation on trout streams are well-known (Lagler 1956, Tebo 1955). Siltation adversely affects trout reproduction, trout food supply and by changing the physical characteristics of the stream to make it unsuitable for trout. Siltation is the major cause of trout habitat destruction in Western North Carolina.

The reconstruction of fourteen miles of North Carolina Route 181 located between Morganton and Linville, North Carolina involved extensive widening and straightening of the existing road bed. Construction in mountainous terrain (1094 to 3779 feet above sea level) resulted in major cuts and fills. Total construction cost approached four million dollars.

As expected, the reconstruction has adversely affected the water quality of Steels and Upper Creeks which parallel either side of the project. Since 1962, these two high quality trout streams have been managed as a wild trout fishery based upon natural reproduction. The objective was to minimize siltation and save the trout fishery of Steels Creek and Upper Creek.

The cooperation of federal and state agencies, Trout Unlimited and private enterprise, was instrumental in the successful preservation of two high quality trout streams. Damage to the streams was minimized and it is estimated that the streams will return to normal within three to five years.

The North Carolina Highway 181 project was not required to have an environmental impact statement and all phases of erosion control were negotiated through the cooperating agencies.

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We would especially like to thank Mr. John Kennedy and Mr. Floyd Brooks of the United States Forest Service, Mr. David Patton and Mr. Robert Crisp of the North Carolina State Highway Commission, and the Asheville and Blyth Construction Companies for their energy, time, and assistance. In addition we thank Trout Unlimited and the 101st Airborne Division from Fort Campbell, Kentucky for volunteering their services. Mr. Hayden M. Ratledge reviewed and criticized the manuscript.

PROCEDURES AND RESULTS

The erosion control measures utilized in construction of Route 181 are listed in Table 1 along with an evaluation of their effectiveness. A diagrammatic view of the location and construction of erosion control methods is shown in Figure 1.

Trout standing crops and reproductive success (Table 2) were estimated using electrofishing techniques. These estimates were made following the two year construction period.

Catch rates as reported to Wildlife Protectors in 1974 were 1.4 trout per hour for Steels Creek and 1.8 trout per hour for Upper Creek (Table 3).

DISCUSSION

Although erosion on the road construction project allowed siltation of both Steels Creek and Upper Creek, the successful reproduction of brown and rainbow trout occurred in the fall of 1973 and the spring of 1974 (Table 2). Further evidence of success in erosion control is the catch rates for trout taken during construction years which are comparable to those catch rates prior to construction (Table 3).

Sources of erosion were the road bed, the surfaces of cuts and fills and waste areas. All three sources were problematic and no one source can be singled out as the worst.

Experience on this project has produced several guidelines for successful erosion control:

- 1) Maintaining minimum areas of exposed earth (work and complete shorter sections of road);
- 2) Timing of earth moving to coincide with periods when revegetation is possible;
- 3) Designing of cuts and fills in critical areas to incorporate erosion control considerations (anticipate erosion);
- 4) Stopping and stabilization of erosion as close to its source as possible;
- 5) Utilization of rapid revegetation and heavy fertilization of revegetated areas;
- 6) Mulching with straw or hay and using jute mats in drainage ditches;
- 7) Acquiring right of way easements or other permission to permit erosion control on or off right of way or on private property if necessary.

Previous road construction projects have allocated from three to five percent of their total funds for erosion control (conversation with Mr. David Patton, Resident Engineer, North Carolina State Highway Commission). The total cost of Route 181 will closely approach four million dollars of which an estimated 15 percent will have been spent to control erosion.

TABLE 1

EVALUATION OF EROSION CONTROL MEASURES
UTILIZED IN RECONSTRUCTION OF ROUTE 181

MEASURE	FUNCTION	EVALUATION
Road Shoulder Maintenance (Berm)	Channels road bed run off into plastic drains and into erosion control devices, used during road bed construction.	Very effective when maintained large enough to effectively channel water thus preventing erosion of surfaces of cuts and fills, mandatory.
Plastic Down Drains	Channels road bed run off into brush barriers minimizing erosion in area of water channelization	Very effective and necessary
Silt Basin	Allows settling of suspended solids	Very effective, mandatory
Brush Barrier	Filters run off from surfaces of of fills and road bed	Very effective, mandatory in forested areas
Temporary Silt Fence	Filters large suspended solids from water run off	Effective in filter action, but temporary nature allows trapped silt to move before stabilization occurs. Extensive use not recommended.
Brush Check Dam	Filters water once it passes initial brush barriers and silt fences.	Not effective, log dams preferred
Log Check Dam	Allows settling of suspended solids during heavy run off peaks, semi-permanent nature allows for stabilization and revegetation.	Very effective
Seeding and Fertilization	Covers exposed earth, use 150 pounds seed with 1200 pounds 8-8-8 fertilizer and 4000 pounds of lime per acre	Very effective
Top Dressing	Applied to 2-1 or greater slopes of cuts and fills to insure ground cover, accompanied by Sericea les-pedega at 50 pounds per acre and 750 pounds 8-8-8 fertilizer per acre	Very effective
Mulching	Breaks impact of rain drops upon earth and seed, holds moisture and soil	Very effective, mandatory
Jute Mats	Placed in median, berm and lateral ditches where road bed run off would erode seed before ground cover becomes established.	Very effective, mandatory

Figure 1.-- Location and construction of erosion control methods

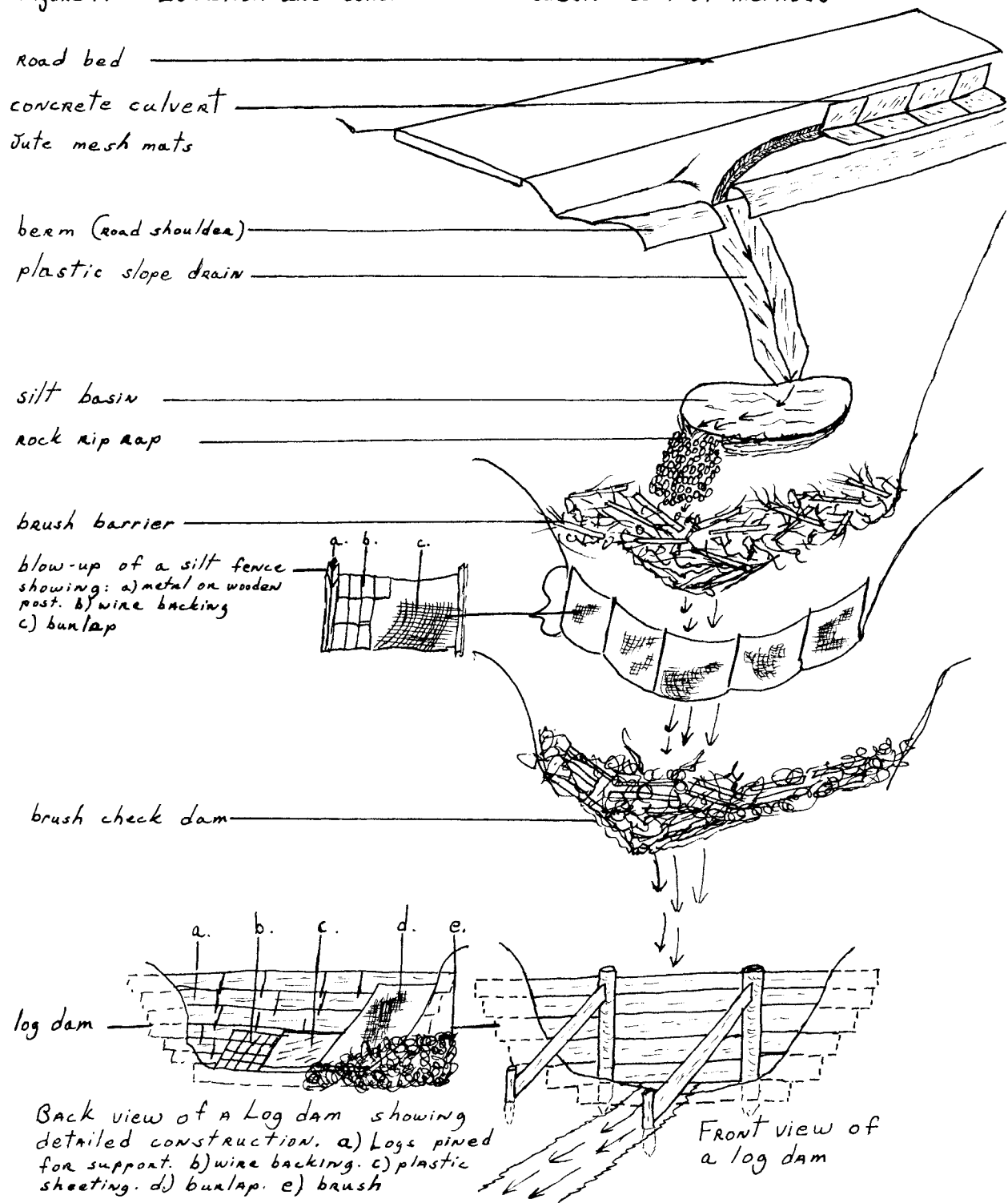


TABLE 2

TROUT ^{a/} STANDING CROP ESTIMATES AND REPRODUCTIVE
SUCCESS FOR STEELS AND UPPER CREEK - 1974

STREAM	POUNDS OF TROUT PER ACRE	TROUT REPRODUCTION PER ACRE (No.)
Right Fork Steels (Silted)	24.2	60
Left Fork Steels (Unaffected)	3.6	120
Gingercake Creek (Unaffected)	34.2	65
Main Steels Creek Below Forks (Silted)	22.3	8
Upper Creek Upper Portion (Silted)	42.1	451

a/ Rainbow (Salmo gairdneri) and brown (Salmo trutta) species combined.

TABLE 3

CREEL CENSUS RESULTS FOR STEELS AND UPPER CREEK

STREAM	CATCH PER MAN HOUR OF EFFORT				
	Pre-construction Years			Construction Years	
YEAR	1970	1971	1972	1973	1974
Steels Creek	1.5	1.5	1.1	1.7	1.4
Upper Creek	1.8	1.4	1.5	1.4	1.8

CONCLUSION

Cooperation, surveillance and public opinion favoring protection of trout habitat have been the keys to the protection of the trout resources of Steels and Upper Creeks. More time and money than ever before has been expended to protect wild trout and their habitat. We hope that the experience gained and the lessons taught by this project will be beneficial to other agencies which will face similar problems in protection of mountain trout resources.

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LIMITING FACTORS ENCOUNTERED IN THE MANAGEMENT OF TROUT IN TAILWATERS

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Abstract.--The major obstacle that prevents nearly every tailwater trout fishery from reaching its potential is unregulated releases for fish management. Under high-flow conditions, the tailwater is not ideal for fishing. Bottom fauna productivity and consequent fish growth are retarded because of extreme flow. High water temperatures and low-oxygenated water sometimes occur during the summer and fall months when there is low flow or no discharge. Some of these problems have been solved by: providing a minimum flow, providing a minimum volume of water during a specified time period, and providing cold water releases that will maintain suitable temperatures in the tailwater for trout. Poor growth rate, predation and intense fishing pressure were once considered limiting factors in tailwaters where fingerling trout were stocked; these factors were nullified by stocking catchable-size trout.

INTRODUCTION

Tailwater trout management procedures have been vastly improved over the past decade as a result of intensive research; many tailwater trout fisheries are now being utilized to their maximum. There remain a few limiting factors that prevent most tailwater fisheries from reaching their maximum potential. It is the purpose of this paper to describe those limiting factors and discuss techniques that will minimize their limiting effects.

DISCUSSION

Fingerling trout, or catchable-size trout, or both are recommended for stocking in tailwaters, based on the criteria described below. In most tailwaters, catchables are preferred because of the lack of an adequate food supply for desirable growth of fingerlings, or the presence of predatory fishes that would cause low survival of fingerlings, or heavy fishing pressure; or any combination of the aforementioned factors. The rate and frequency of stocking trout are determined by fishing pressure and harvest. Boat fishing has been instrumental in increasing the fishing success and harvest on tailwaters having sufficient flow.

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Certain tailwaters that were once stocked with fingerling trout are now being stocked with catchables because of overexploitation. The trout fishery on the White River below Bull Shoals Lake in Arkansas was initially maintained by stocking fingerling trout (Baker, 1959). Eventually, because of intense fishing pressure, stocking of catchable-size trout was necessary to maintain a quality fishery. Little (1967) recommended additional stockings of catchable trout in the Dale Hollow tailwater in Tennessee to reduce pressure on fingerlings that were also stocked. It may be desirable to impose a size limit on trout in situations similar to that below Dale Hollow Dam, thereby essentially preventing the harvest of fingerlings before they are able to grow and provide a quality fishery. A size limit would permit fingerlings to grow to a preferable size, and a quality fishery would be maintained without supplemental stocking of catchables. Their growth potential would be fully utilized in the tailwater (e.g., trout grow in the Dale Hollow tailwater at a rate of 0.9 inch per month), and rearing and stocking costs would be reduced.

A major problem of great complexity often encountered in tailwater trout management is that of erratic flow. High flows create water conditions that are unfavorable for fishing. If high flows could be limited, the tailwater would receive more fishing pressure, resulting in an increase in harvest. Boles (1974*) reported that the major fishing effort on the Norris tailwater in Tennessee occurred during low flow or no discharge periods, particularly on the weekends. High flows were also detrimental to bottom fauna productivity and trout growth below Norris Dam.

The Norris tailwater receives low-oxygenated water in the fall from the hypolimnion of Norris Lake, which is also detrimental to trout growth. The growth rate and condition of trout in the fall of both 1971 and 1972 decreased because the tailwater was deficient in dissolved oxygen (DO). During the most critical period in 1971, DO content remained below 4.5 ppm for 9 miles below the dam. The oxygen situation was improved, however, when the TVA began to schedule daily 2-hour shutoffs that allowed DO content to recover to 4.0 ppm at a distance of nearly 3 miles below the dam. Several aeration methods are available to correct the problem of low DO concentrations (described by Ruane, 1972). Most of these methods need further refinement before they become efficient enough to be economically feasible.

Elevated water temperatures during the summer and fall months are a problem below Tenkiller Ferry Dam on the Illinois River in Oklahoma. Hicks (1966) recommended that the U.S. Army Corps of Engineers (COE) provide a minimum flow of 25 to 50 cfs, and water temperatures of less than 70F. Water temperatures were the main limiting factor in the tailwater below Bull Shoals Dam before the COE agreed to provide water temperatures below 70F.

A minimum flow of 5 million cubic feet during any 48-hour period was assured by the COE for the Dale Hollow tailwater, in order to maintain water temperatures suitable for trout. A continuing effort is needed to secure cooperation from the tailwater regulatory agency in following the discharge program recommended by the tailwater fishery manager.

*Personal Communication

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RECLAMATION OF DAMAGED STREAMS AS A TOOL IN RESOURCE MANAGEMENT

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INTRODUCTION

For decades water resource managers, fisheries biologists, laymen, and others have viewed with dismay the degradation of increasing numbers of streams by a vast array of industrial, agricultural, and domestic wastes. A national movement toward environmental awareness, coupled with strict legislation such as the Federal Water Pollution Control Act Amendments of 1972, offer the prospect for reversal of this pollution trend.

While the amended Act implies "zero discharge" by 1985, realities such as the current energy crisis and legitimate economic complaints may cause such a goal to slip. Hopefully, resulting compromises will be ones in which discharges are based upon known assimilative capacities of the receiving streams on a regional watershed basis. Whatever the tactic, extensive pollution abatement already under way will probably continue, even under adverse political and economic circumstances. Assuming functional biological recovery, currently degraded streams could contribute significantly to the stream fishery resource. The following is a discussion of factors which influence biological recovery of damaged streams and includes some case histories of stream recovery.

FACTORS AFFECTING STREAM RECOVERY

Biologists have long recognized that individual organisms and communities of organisms must be resilient and adaptable to survive even the adversities of

natural events. Add to the vagaries of nature the innumerable perturbations man exerts upon aquatic systems and these attributes become even more important.

Cairns et al. (1971) state that aquatic ecosystems have the ability to assimilate a certain amount of waste material and maintain near normal function. They found that when a system's assimilative capacity is overloaded, the system is disrupted, and the rate of recovery depends upon (1) severity and duration of the stress, (2) number and kinds of associated stresses, (3) recolonization of the area by useful aquatic organisms, and (4) residual effects upon nonbiological units (e.g., substrate, etc.). Larimore et al. (1959) stressed the importance of the ratio of damaged to undamaged reaches of a stream in their study of the rate of reinvasion of a small Illinois stream by fish and invertebrates. Additionally, they found that within a given year the rate of reinvasion is strongly influenced by water levels and seasons of the year.

While any one of the factors mentioned above may affect the rate and extent of biological recovery, there are only two circumstances in which recovery would not take place: (1) if there are residual effects which make the area unsuitable for diverse communities of aquatic organisms; or (2) if there is not an adequate pool of organisms outside the affected area for effective recolonization. While extreme instances of these two circumstances are rare, it is equally uncommon that their influence upon recovery processes cannot be measured to some degree. The following case histories illustrate the manner in which conditions discussed above may affect stream recovery.

TURBIDITY AND SILTATION

Hill's investigation of the recovery of damaged streams following manganese strip mine reclamation on the headwaters of the South Fork Holston River (1971)

indicated that, six years after reclamation of spoil areas by the U. S. Forest Service, functionally complete stream recovery had taken place. While recovery probably occurred earlier, no observations were available for those periods. Although extreme turbidities and siltation affected the entire lengths of these tributary streams and reduced faunal populations by 90 percent or more, recovery in streams draining fully reclaimed areas was complete in that conservatively estimated time period. However, streams draining partially reclaimed areas showed no more improvement than those below unreclaimed spoils. While this must be termed incomplete abatement, similar results could be expected from residual effects.

ALKALINE STRESS

In June 1967 a fly ash holding pond at a power plant on the Clinch River broke, releasing approximately 130 million gallons of caustic materials. It was estimated that 216,000 rough and sport fish were killed in 90 miles of the stream in Virginia and Tennessee. The Virginia State Water Control Board reported a drastic reduction in the number and kinds of bottom-dwelling fish food organisms for 77 miles below the spill. Snails and mussels were eliminated for 11.5 miles downstream of the spill.

Two years after the spill, Cairns et al. (1971) reported the reestablishment of diverse communities of fish and bottom fauna adequate to support a productive sport fishery, even though recovery still was not complete. Molluscs especially were slow in recolonizing, and the plant continued discharges of some effluents. Although the stress in this case certainly was severe, the absence of a residual effect, combined with extensive areas from which recolonization could take

place made recovery rapid. The fact that recovery still was not complete after two years can probably be ascribed in large part to the high ratio of damaged to undamaged reaches of the river.

TOXIC INORGANICS

A large chemical plant located on the banks of the North Fork Holston River approximately 80 miles above its mouth discharged large quantities of chlorides and other inorganic substances into the river for more than 70 years. Over extended periods of time, the plant was discharging approximately 950 tons per day of calcium chloride and 575 tons per day of sodium chloride. Beginning in the 1950's the plant began using mercury in a caustic soda-chlorine process, and substantial amounts of the mercury found its way into the North Fork (Bailey, 1974). Unable to meet water quality standards, the plant closed July 1972. Hill,et al. (unpublished) found that after two years limited recovery of fish and bottom fauna communities has taken place in the lower part of the river, but that there is no evidence of substantial recovery in the river several miles downstream of the plant. River sediment and fish tissue analyses (Bailey, 1974) show the persistence of high mercury concentrations which can probably be attributed to a continuing input from extensive abandoned waste lagoons (Hill, unpublished). Again, this is an instance in which incomplete abatement limits recovery.

An additional limiting circumstance in the recovery of the North Fork Holston River is the nonavailability of certain groups of organisms for recolonization. While it appears that there is an adequate pool of fish and aquatic insect species for recolonization, species of mussels in the river have been reduced from more than 30 to about eight species and are not available in tributary streams or the

South Fork Holston which the North Fork joins. Hopefully, TVA and other agencies, by working with the industry involved, can eliminate or reduce the continued input of materials from the waste lagoons, and then attempt faunal transplants of important organisms not available for recolonization.

CONCLUSIONS

In summary, although a complex of factors influence the potential of a stream to undergo biological recovery, two of the most important criteria are: (1) the absence of limiting residual effects or the continued input of detrimental substances; and (2) the availability of recolonizing populations of organisms adequate for the reestablishment of diverse, functional biotic communities.

The prospects for broadening the base of stream fishery resources through the reclamation of damaged streams are very promising. Agencies concerned with pollution abatement should examine each situation carefully with regard to residual effects or incomplete abatement. Those agencies concerned with management of the stream resource should give consideration to the possibility of influencing faunal community structures through appropriate faunal transplants.

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RESEARCH IN AQUATIC HABITATS AT THE SOUTHEASTERN STATION

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Abstract.--Research is urgently needed to provide technology necessary to restore, maintain, or improve approximately 20,000 miles of trout stream in the southern Appalachian Mountains. Studies at the Coweeta Hydrologic Laboratory in western North Carolina have shown that man's activities change the quantity, quality, and stability of water flowing from forest land, and that land management practices which affect these parameters also affect the stream biota. A new program of aquatic habitat research has been started at the Southeastern Forest Experiment Station. Intensive research is needed to meet demands of trout fishermen.

Additional keywords: Trout, research program, research approaches.

Each year, millions of Americans visit the Appalachians, where they camp, picnic, fish, or just relax and enjoy the soothing qualities of flowing water. Approximately 900,000 sportsmen fish some 20,000 miles of trout water in the southern Appalachians. The popularity of sport fishing continues to grow, and mountain streams in our national forests are currently receiving increasing pressure from some 10 million sport fishermen who live within driving distance of this region. Despite this large and growing public interest, the management of trout fisheries has not received the attention on public lands that managers extend to wildlife. Most land managers appreciate the recreational aspects of sport fishing and the importance of protecting watersheds and water quality. But they have limited knowledge about trout stream management or the ecology of aquatic resources in general.

There are three elements involved in managing a trout stream for sport fishing: the environment, the fish, and the angler. From the management or research point of view, these elements are not mutually exclusive. The environment and fish are parts of an intricate ecosystem upon which the angler is superimposed as an external predator. We know most about managing trout. Population structure and arrangement, territoriality, physiological functioning, attributes of different species of trout, etc., have all been studied in detail. We know considerably less about the angler and what motivates him to seek certain experiences in conjunction with his pursuit. For the most part, confirmed trout fishermen seem to be independent, intolerant, and demanding when it comes to land management activities that might influence their sport. Questions outnumber answers about managing or improving stream environments, because such environments reflect complex patterns of local geology, climate, and vegetation. Such patterns determine the chemical, physical, and biological features of streams, and these features, in turn, determine the condition of the habitat for trout. Research is needed to define those characteristics of trout habitat in the Appalachians which are subject to management and intentional and unintentional modification. Such knowledge will provide a sound basis for management decisions that will protect and possibly enhance the trout resource for future generations of fishermen.

Our program for aquatic research is new; we are emphasizing trout habitat, recognizing that other aquatic habitats are also involved and equally important. This paper indicates the relevancy of past research by the U.S. Forest Service and describes trout habitat research that is proposed or currently underway at the Southeastern Station.

PAST RESEARCH

Research over the past 40 years at the Coweeta Hydrologic Laboratory in western North Carolina has shown that water is a most sensitive indicator of watershed activities. Early experiments at Coweeta documented the effects of mountain farming, logging, and grazing practices on water quality and yield (Lieberman and Hoover, 1948; Greene, 1950; Dils, 1952; Johnson, 1952). Later studies verified that water yield and timing can be changed substantially by drastically altering forest cover (Hewlett and Hibbert, 1961; Hibbert, 1966; Swank and Miner, 1968). Other studies examined road design, construction, and location with respect to erosion and water quality and pointed out the importance of minimizing soil movement during timber harvest (Hursh, 1935; Lieberman and Hoover, 1948; Jones, 1955).

Some of the first documented evidence of the detrimental effects of logging on stream biology was collected at Coweeta by the North Carolina Wildlife Resources Commission in the early fifties. This investigation established relative values for invertebrate biomass, measured effects of siltation and stream zone clearing on bottom organisms and temperatures, and established feeding preferences of rainbow, brook, and brown trout (Tebo, 1955; 1957). Later studies showed that stream temperatures could be increased, decreased, or left unchanged depending on the type of cutting practice employed (Swift and Messer, 1971), and that temperature increases caused by clearcutting could be moderated by streamside buffer strips (Swift and Baker, 1973).

In conjunction with the IBP Program, the processing structure of several small streams was partially revealed by taxonomic and trophic investigations. Studies showed that the benthic fauna in woodland streams can be altered by cutting treatment and forest-land conversion (Woodall and Wallace, 1972) and revealed nutrient pathways and the capacity of small streams to alter and process various kinds of material (Woodall, 1972).

Many excellent studies have been conducted at Coweeta on small watershed streams. Investigations clearly show that man can and does change the quantity, quality, and stability of water flow from forest land, and that practices which affect these parameters also affect the stream biota. These findings provide a valuable beginning for the biologist concerned with the trout resource in the Appalachians.

CURRENT RESEARCH

The Program

Streams are biological units which process and utilize organic and inorganic materials of terrestrial origin. Such units are sensitive to change, and activities on the land which disrupt or change the material balance between the stream and the watershed are potentially harmful to certain portions of the stream biota. Trout are very sensitive to chemical, physical, and biological changes in their habitat. While such sensitivity has eliminated trout from many miles of once productive water, it simplifies the research problem. The fish themselves are excellent response variables which can be used to determine how changes in habitat affect them.

Our research program is designed to develop the technology needed to protect and enhance the aquatic environment and the trout fishery in the Appalachian Mountains while maintaining and enhancing other resource values. We hope to (1) determine how variations in water quality, food cover, and fishing pressure influence trout production; (2) establish environmental standards for logging, road construction, land clearing, and mining to prevent adverse impacts on trout; and (3) provide methods and technology for restoring and maintaining productive capacities of trout streams.

Research Approaches

Our approaches, when possible, are designed to predict the influences of land management practices on stream biology. Effects of timber harvesting, roading, construction, and other forms of disturbance can be evaluated through land-use impact studies. This approach is readily applicable to management situations which could not be duplicated experimentally. The disadvantage of this approach is that it does not fully explain the reason for observed changes, and the results may not be directly applicable to other environmental situations.

Another approach, and the one we will emphasize, is habitat analysis. This is a basic approach which relates population characteristics of trout and other organisms to the stream environment. When possible, observations will be made over a range of stream types, rather than one as in conventional case history studies. This technique adds realism to our models by considering the oftentimes overlooked dimension of natural variation and its effects on results.

Current Studies

We recently began research to determine reasons for the wide disparity among population densities, size of fish, and composition of trout in our mountain streams. One facet of this work compares the growth rate of different fish stocks with the relative abundance of the food and of the fish population. Another facet relates population density to the physical and chemical characteristics of streams. By measuring trout density, species composition, and growth characteristics and relating these factors to the availability of food and cover, water chemistry, and stream morphology, we will begin assembling fundamental data needed to formulate suitable management practices.

In one opportunistic study, we measured the effects of a severe flood on protective cover for a large known density of trout. The flood significantly reduced quantities of logs, undercut banks, and brush, cover units used by large fish in study sections. These losses were offset by increases in the cover-affording capacity of stream-bottom material. The size of cover units available to fish after the flood was disproportionately reduced, however. As a result, study sections now primarily support a larger density of smaller size trout.

We are also studying the effects of a small waste treatment facility on a trout stream. Results from this study will show what effects nutrients have on the biology of relatively sterile receiving waters.

We are planning several important new studies. One will investigate the effects of cable logging on the aquatic resource. Such logging systems may greatly reduce formation and transport of erosion products which frequently damage streams during and after conventional timber-harvest operations. Another study will evaluate forest fertilization and its effects on stream biology. Fertilization may benefit trout by increasing overall stream productivity.

Future Direction

Our proposed program will require a team of researchers including specialists in fisheries management, aquatic ecology, and entomology. We will enlarge the overall research effort through cooperative programs with neighboring universities, State and Federal agencies, and interested conservation groups.

We must closely examine existing food chains and webs available to trout. Efforts must be made to relate productivity of food organisms to water chemistry, food availability, and physical habitat. We must determine how the invertebrate biota is affected by land management and how the distribution, composition, and abundance of key invertebrates vary seasonally.

We must begin to intensively evaluate the effectiveness of current guidelines for roading and logging practices as protectors of the aquatic environment. We must identify geologic, moisture, and soil conditions for which modified or new criteria are needed.

In light of current demands for both trout fishing and forest products, we must also consider permissible ranges of alterations to the stream biota. Some alterations may benefit the fishery by, for instance, increasing the supply of available food or even cover without stressing other portions of the habitat. Perhaps the careful and limited removal of streamside vegetation could increase the growth of periphytic plants sufficiently to appreciably raise production of grazing aquatic organisms. Or, perhaps, changing the structure or species composition of streambank vegetation could provide additional cover and more nutritious or decomposable material to the stream biota.

These are some questions we hope to answer. Studies which deal with various facets of protection and those which have immediate management potential will receive priority in our research program.

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THE PLANNING APPROACH TO TROUT MANAGEMENT

Joseph R. Fatora^{1/}

Abstract.--Trout management in the Appalachians under today's conditions with increasingly heavier resource demands should follow an orderly planning process utilizing resource survey and demand input and evolving to an operational plan considering the trout management area as a unit or logical subunits. Classical management techniques of habitat modification and population manipulation should be utilized when feasible and waters identified as high-use areas and native fish management waters managed with appropriate techniques.

Additional keywords: Survey data, access, regulations.

Trout management practices have classically involved modification of physical or chemical parameters to enhance the available habitat. Modifications that have been employed and continue to be utilized by agencies responsible for management include installation of habitat alteration structures such as splash dams, digger logs, cover logs, gabions, rock rip-rap, and similar devices. These devices are used variously to increase pool ratio, provide cover, increase water depth, or correct erosion problems. Other methods employed include installation of spawning channels or boxes, construction of fishways for spawning runs, use of barriers to prevent downstream ingress, addition of chemicals for artificial enrichment or alteration of pH, and revegetation of stream banks.

Population manipulation also has long been used, including rough fish control, stream renovations, introduction of exotic species, continually supplementing the population with stocking, or planting of eggs in gravel bars.

These classical methods have had varying success under different sets of conditions. The experienced trout manager knows what techniques to apply and can produce successful results under the proper circumstances.

Managers are constantly being reminded that fishing "ain't what it used to be". Mullan (1960) expressed this very well--"Trout fishing isn't what it used to be and it never was: Regardless of how hard nature works towards primeval conditions...it is obvious that the whole delicate balance . . . will never again be what it once was . . . The clock cannot be turned back." This fact is incontestable. Many miles of trout water have been seriously degraded and will remain so. Conversely, trout species are now found where they never occurred naturally. The productivity of trout waters also must accommodate many more fishermen than in the "good old days". Looking backward in time with misty eyes is a luxury that managers cannot afford.

The basic underlying concept to management of Appalachian trout waters under today's conditions with increasingly heavier demands upon the resource is management of the resource as a unit consisting of variably managed subunits. This necessitates that fishery managers be planners, a function they have historically assumed. However,

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this is fraught with problems as pointed out by Libby (1974) -- "The mythology of comprehensive planning can generate the appearance of action without the substance. The products of planning--maps, charts, projections--can lull plannees into an illusion of improvement.

However, the maps, charts, and projections are a necessary prerequisite to the planning process, but should not be construed as the end result. The first step involves collection of survey data. The survey data can be gathered and collected in a format suited to the purpose and desired result. These data can be applied toward developing various classifications based on legal, ecological, sanitation, or management criteria. Seehorn (1970) devised a survey format for evaluating and classifying trout waters that is effective and economical. Fish (1968) compiled the survey and inventory data of North Carolina waters. Information of this type is of direct value to future planning efforts. The input data collected as a result of the State Comprehensive Outdoor Recreation Plan in the cooperating southeastern states is definitely of value. This developed data on existing habitat parameters and on supply, demand, and need. Other data have evolved from the National Surveys of Fishing and Hunting (Department of the Interior) made at 5-year intervals beginning 1955. These examples provide the input--the maps, charts, and projections--which are of little value if not followed to conclusion, the planning effort.

Comprehensive planning, the popular buzzword and nonentity of Libby (1974), is the next step in the usual planning process by planners. This is very often the end step and often only of theoretical value. Attempts at implementation often end in utter failure. This should be the first step in the planning process for recreational fisheries management--not the end result--but provide for development of an overall plan for implementing detailed planning. The detailed plan, or operational plan, is the end result, and an enormous effort involving managers, not planners, with an intimate knowledge of the resource for which they are managing and a recognition of the fundamental significance of fishing in outdoor recreation (Stroud, 1968).

Another problem muddling the planning process is the number of state and federal agencies involved in planning. The in-thing today is to have a plan. It becomes quite obvious that several agencies planning for the same parcel of land will develop inconsistent plans. The only way to resolve this inconsistency is a single coordinated planning effort.

Planners tend to maximize, an inherent falacy in most comprehensive planning. However, trout managers are at inconsistent odds with themselves. At one end of the spectrum they maximize to get the highest use of the resource possible, and at the other end, they tend to manage a resource for their conception of trout fishing, fishing on an inaccessible stream for native trout with artificial lures.

Boiling this discourse down to basic principles more applicable to the trout manager, he must make use of the available input data on the resource and anticipated or generated demand and plan accordingly. It is during this operational planning phase, or formulation of the implementation program, that the trout manager can satisfy both ends of the management spectrum. Much emphasis has been placed upon optimum as opposed to maximum use of a fishery resource. There definitely is valid reasoning in planning for and obtaining use in excess of optimum on certain waters. These would be waters located near population centers, on the periphery of the main trout management area, or streams with well developed access patterns. These waters would, because of their location, size, or access, be able to absorb a high degree of fishing pressure, and would be heavily stocked to the anticipated demand. As an example, annual pressure was estimated at 8100 anglers/km during 1973 on Tallulah River, Georgia (England and Fatora, 1974). This stream is accessible by a proximate parallel road with developed campsites.

Waters other than those designated for high use should be classified and managed based on existing or proposed access patterns and on biological parameters. Of primary importance here is the access patterns of the area to be managed, especially on small, easily fished streams. Large rough waters are more buffered against fishing pressure, but they too are susceptible. Access should be controlled as far as feasible on streams identified for native fish management. The desirable situation is to prevent future road access to existing high quality native fish waters. As soon as access is provided, these streams become degraded in quality, both from the physical impact of the road itself, and the increased angling pressure.

Another factor of distinct importance beyond the effect of the existing and planned road net in the trout management area is the pattern of regulations and stocking applied to the various waters. Regulations are a highly valuable management tool, disregarding those implemented for traditional or moral reasons.

Creel limits may be of some value on stocked streams to distribute the catch among more anglers, but are of relatively little value in preventing overexploitation of a native stream unless unduly restrictive. England (1974) in summarizing data on stocked Georgia streams reported 24% of the anglers attaining the limit under an 8-trout limit and 15% under a 10-trout limit. Hunt, Brynildson, and McFadden (1962) found little effect of a liberal 10-trout limit on harvest on a native brook trout stream.

Minimum size limits are effective in controlling overexploitation. This insures a population under a selected minimum size depleted only by natural mortality and hooking loss. Minimum size limits can also be utilized for maintenance of special management fisheries, such as catch-and-release (Fatora, 1970) and trophy streams (England and Fatora, 1974).

The main management value of regulations other than utilization to directly prevent overexploitation is in control of fishing pressure. Restrictive regulations have a tendency to reduce pressure (Shetter and Alexander, 1962; Fatora, 1970; Ball, 1971; Klein, 1972). These special regulations can range from artificials only and fly-fishing only waters to catch-and-release and trophy streams. The usual argument against such practices is discrimination against the majority of anglers by restricting fishing to an elite group. Some trout managers find it hard to justify limiting pressure and not obtaining heavier use. However, to manage streams as native streams with optimum use under current pressures exerted upon the resource, some method of reducing the pressure becomes mandatory. Restrictive regulations can accomplish the reduction in pressure and provide what is commonly referred to as a quality experience.

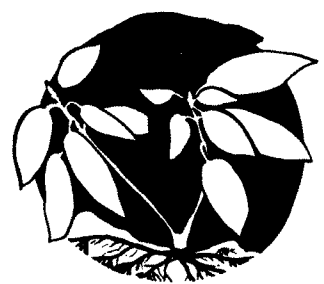
The planting of catchable fish in small numbers throughout the season, generally referred to as supplemental stocking, has long been in common practice. The effect of stocking on the resident population has been suspected by managers, but recent data (Vincent, 1972) have revealed the depression of a wild trout population by catchable plants in a Montana stream. This study has reinforced the gut feeling of many trout managers. Thus, wild trout populations should be managed as such and not disrupted by planting of hatchery stock.

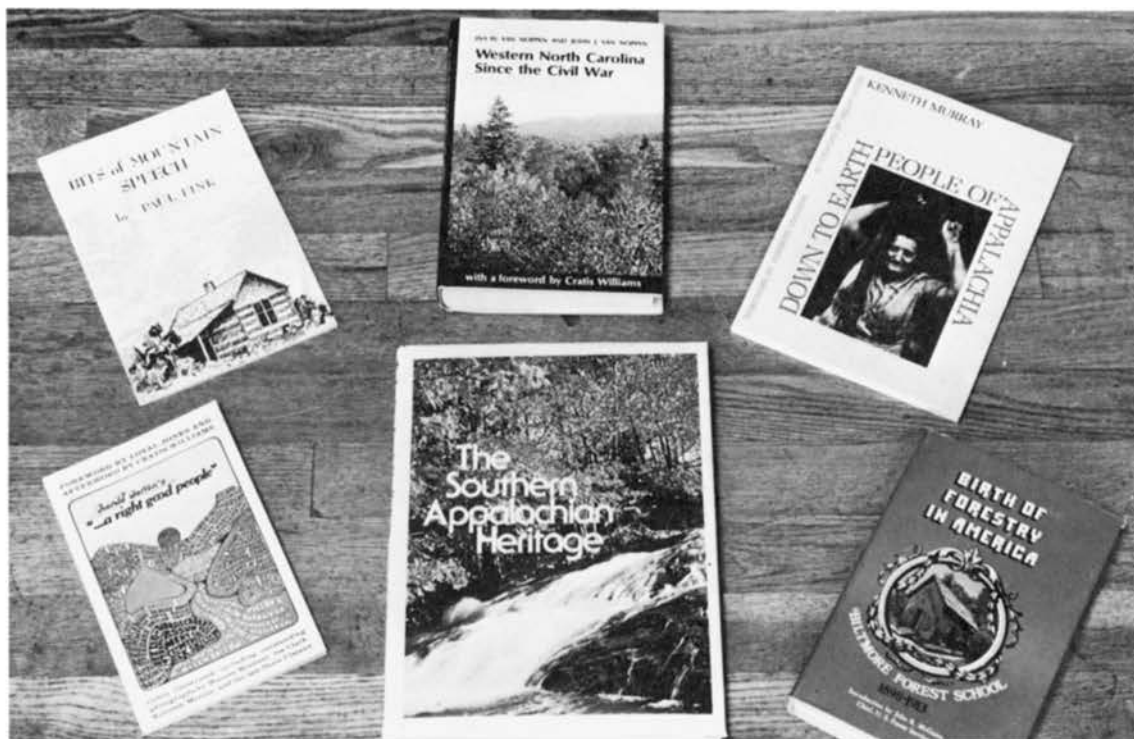
The reduction in pressure through application of restrictive regulations probably has more impact when anglers have access to a high use stream in the same locality. Georgia's wildlife management areas generally are provided with at least one high use stream with streams under native management with either state-wide or special regulations in effect. The high use streams with good access and camping areas absorb most of the pressure.

In summation, the trout manager must utilize the input data of the planning process such as resource survey and classification data and on demand data and proceed through the planning process to development of an operational plan. Plans should consider the trout management area as a unit or logical subunits. Classical management techniques of habitat modification and population manipulation certainly should be applied. Trout waters identified during the planning process as existing or potential high density use areas or as native fish management waters can then be managed utilizing appropriate management techniques.

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